MOBIUS INSTITUTE

VIBRATION TRAINING QUICK REFERENCE

GLOSSARY
DIAGNOSTIC GUIDE
USEFUL CHARTS AND TABLES

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Table of Contents

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Glossary

Diagnostic Guide

Ski-Slope D-3
Raised Noise Floor D-4
Dynamic Imbalance D-6
Static Imbalance D-7
Couple Imbalance D-8
Imbalance: Overhung Machines D-9
Imbalance: Vertical Machines D-10
Eccentric Rotor or Gear D-11
Eccentric Sheaves D-12
Misalignment D-13
Angular Misalignment D-14
Parallel Misalignment D-15
Bent Shaft D-16
Cocked Bearing D-17
Looseness D-18
Rotating Looseness D-19
Structural Looseness D-20
Pedestal Bearing Looseness D-21
Rotor Rub D-22
Journal Bearing Clearance D-23
Oil Whirl D-24
Resonance D-25
Rolling Element Bearing Wear D-26
Pumps/Fans Blade/Vane Pass D-29
Flow Turbulence D-30
Cavitation D-31
Reciprocating Machines D-32
Stator Eccentricity D-33
Soft Foot D-34
Eccentric Rotor D-35
Rotor Bow D-36
Cracked or Broken Rotor Bars D-37
Loose Rotor Bars D-38
Loose Rotor D-39
Loose Stator Windings D-40
Lamination Problems D-41
Loose Connections D-42
Gear Faults D-43
Gear Tooth Wear D-44
Gear Tooth Load D-45
Gear Backlash D-46
Eccentric Gears D-47
Misaligned Gears D-48
Cracked or Broken Tooth D-49
Hunting Tooth Frequency D-51
Coupling Faults D-52
Worn or Loose Belts D-53
Eccentric Sheaves/Pulleys D-54
Misaligned Sheaves/Pulleys D-55
Belt Resonance D-56
External Noise D-57

Please see inside back cover for chart of symptoms and relevant page references.

Table of Contents
(Continued...)

Useful Charts and Tables

Unit Conversions F-3
1X Vibration Levels F-4
Vibration Severity Chart F-5
ISO 10816-1 Vibration Severity Chart F-6
ISO 10816-3 Vibration Severity Chart - Velocity F-7
ISO 10816-3 Vibration Severity Chart - Displacement F-8
Belt forcing frequency F-9
Bearing Forcing Frequencies F-10
Transducer Linear Range F-11
Transducer Operating Regions F-12
Transducer Frequency Response for Magnets on Curved Surfaces F-13
Transducer Frequency Response for Magnets on Flat Surfaces F-14
Transducer Frequency Response for "Stingers" or "Hand Held Probes" F-15
Transducer Frequency Response Curves F-16
Transducer Frequency Response Curves
for Accelerometers with Different Sensitivities F-17
Transducer Effectiveness Regions F-18

Glossary

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Absorber

A device designed to reduce the intensity of vibration.

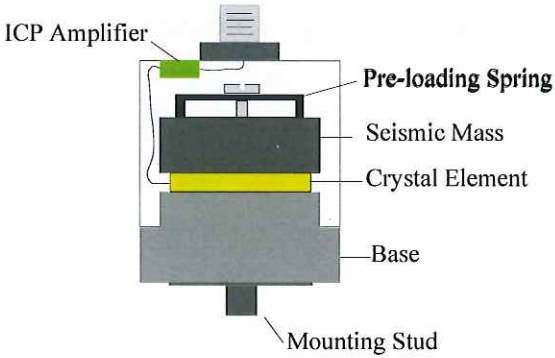
Acceleration

The time rate of change of velocity, usually measured in Gs in the English system of measurements, and in meters per second (m/s2) in the SI system. It is interesting to note that the G is not actually a unit of acceleration, but is the magnitude of the acceleration due to gravity at the earth's surface. This causes some undue complexity in converting parameters between acceleration, velocity, and displacement. 1g = 9.80665m/s^2 = 980.665 cm/s^2 = 386.089 in/s^2 = 32.174 ft/s2

Accelerometer

A transducer whose electrical output is directly proportional to acceleration over a fairly wide frequency range. In a piezoelectric accelerometer, as the vibration force is applied to the crystal, a charge is produced that is proportional to the magnitude of the force. This charge is then amplified and can be displayed either as a time waveform or a frequency spectrum after undergoing an FFT.

An acceleration measurement can be transformed into a velocity display via integration. Integrating again, will produce a displacement display.



Piezoelectric ICP Accelerometer

The high frequency response of an accelerometer is limited by its inevitable internal mechanical resonance. Most common accelerometers respond down to one or two hertz, and some special accelerometers respond all the way down to zero frequency, sometimes called "D. C. response".

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A

Accuracy

The accuracy of an instrument is an indication of how close a measured reading is to the true value.

A/D Converter

A device that changes an analog signal such as voltage or current into a digital signal (consists of discrete data values).

Aliasing

A phenomenon that can occur whenever a signal is not sampled at greater than twice the maximum frequency component. Causes high frequency signals to appear at low frequencies. Aliasing is avoided by filtering out signals greater than 1/2 the sample rate.

Alignment

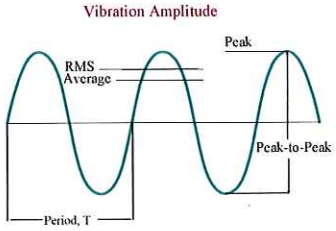
A condition where the components of a machine are either coincident, parallel, or perpendicular, according to design requirements. Misalignment is the condition where the desired coincidence, parallelism, or perpendicularity is not achieved, and it causes abnormally high wear and power consumption in the machine. The procedure to correct misalignment is also called "alignment".

Amplification Factor (Synchronous)

A measure of the susceptibility of a rotor to vibration amplitude when rotational speed is equal to the rotor natural frequency (implies a flexible rotor). For imbalance type excitation, synchronous amplification factor is calculated by dividing the amplitude value at the resonant peak by the amplitude value at a speed well above resonance (as determined from a plot of synchronous response vs. rpm).

Amplitude

The magnitude, or amount, of displacement, velocity, or acceleration, measured from the "at rest" value. The amplitude of a vibration signal can be expressed in terms of "peak" level, "Peak-to-peak" level, or RMS level. It is somewhat of a de facto standard that Displacement is peak-to-peak, Velocity is peak, and Acceleration is RMS.



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Angular Frequency

The angular frequency (ω) is the torsional vibration frequency in radians per second or hertz (Hz). The angular frequency is also known as circular frequency.

Anti-Aliasing Filter

A low-pass filter designed to filter out frequencies higher than 1/2 the sample rate in order to prevent aliasing.

Anti-Friction Bearing

See Rolling Element Bearing.

Asymmetrical Support

Rotor support system that does not provide uniform restraint in all radial directions. This is typical for most heavy industrial machinery where stiffness in one plane may be substantially different than stiffness in the perpendicular plane. Occurs in bearings by design, or from preloads such as gravity or misalignment.

Asynchronous

Vibration components that are not related to rotating speed (also referred to as non-synchronous).

Attachment Pad

A transducer mounting pad is called a "block" or "attachment pad". Attachment pads (bronze or stainless steel) are located on the machines where measurements are required. The attachment pad ensures a good transfer of vibration data through to the transducer - a strong, consistent force always in exactly the same position.

Auto Spectral Density (ASD)

The measure of acceleration per Hz of analysis bandwidth - also known as Power Spectral Density, PSD. The area under ASD curve is defined as the gRMS of acceleration.

Auto Spectrum

An auto spectrum or power spectrum displays magnitude which represents the power at each frequency, and which has no phase. R.M.S averaging produces an auto spectrum.

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Averaging

In performing spectrum analysis, regardless of how it is done, some form of time averaging must be done to determine the level of the signal at each frequency. In vibration analysis, the most important type of averaging employed is linear spectrum averaging, where a series of individual spectra are added together and the sum is divided by the number of spectra.

Averaging is very important when performing spectrum analysis of any signal which changes with time and this is usually the case with vibration signals of machinery. It is especially important for low-frequency measurements, which require long averaging times to achieve a good statistically accurate estimate of the spectrum. Linear averaging smoothes out the spectrum of the random noise in a spectrum making the discrete frequency components easier to see, but it does not actually reduce the noise level.

Another type of averaging which is important in machinery monitoring is time domain averaging, or time synchronous averaging, which requires a tachometer to synchronize each "snapshot" of the signal to the running speed of the machine. Time domain averaging is very useful in reducing the random noise components in a spectrum, or in reducing the effect of other interfering signals such as components from another nearby machine.

Axial

Parallel to the centerline of a shaft or turning axis of a rotating part. Axial vibration measurements are an important part of machinery analysis. See also Orientation.

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Balance

When the mass centerline and rotational centerline of a rotor are coincident.

Balancing

The adjustment of the mass distribution of a rotating member so that the forces on the bearings due to centrifugal effects are reduced to small values. The rotor is balanced if the center of the mass distribution is coincident with the center of rotation. Balancing reduces power consumption in machines, reduces vibration levels, and increases bearing life, sometimes greatly.

Band Alarm

Band alarms are a standard method for establishing alarm limits on a spectrum. For a particular measurement point, bands are defined along the frequency range around frequencies of interest (for example around 1X, 2X, 3X-6X, etc.). "Warning" and "fault" alarm limits set for each of these bands. Most vibration analysis packages allow six bands to be defined.

Bandwidth

The difference in frequency between the upper and lower cutoff frequencies of a band pass filter or other device is called the bandwidth of the filter or device.

Baseline Spectrum

A vibration spectrum of a machine which is considered in good condition. The baseline spectrum may be an average of spectra recorded from several machines of the same type. The baseline spectrum is also sometimes called a reference spectrum, and is used as a basis for comparison to spectra recorded as the machine continues to operate.

Beats

Periodic variations in the amplitude of an oscillation resulting from the combination of two oscillations of slightly different frequencies. The beats occur at the difference frequency.

Beat Frequency

The absolute value of the difference in frequency of two oscillations of slightly different frequencies.

Bias

Refers to a more or less persistent tendency for the measurements, as a group, to be too large or too small.

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BIN

A frequency bandwidth determined by Fmax divided by the number of lines of resolution. While commonly referred to and represented by a line of resolution, a BIN contains a bandwidth of frequencies. (Refer to LINE OF RESOLUTION).

Blade Pass Frequency (Pumping Frequency)

BLADE PASS FREQUENCY (PUMPING FREQUENCY): A potential vibration frequency on any bladed machine (turbine,

axial compressor, fan, pump, etc.). It is represented by the number of fan blades or pump vane times shaft rotating frequency.

A vibration spectrum of a machine which is considered in good condition. The baseline spectrum may be an average of spectra recorded from several machines of the same type. The baseline spectrum is also sometimes called a reference spectrum, and is used as a basis for comparison to spectra recorded as the machine continues to operate.

Bode plot

The magnitude of vibration at 1 x shaft speed, and its phase relative to shaft position plotted against running speed.

Bow

A shaft condition (rotating machinery) in which the shaft centerline is not straight.

Broadband

An overall vibration level which encompasses a wide range of frequencies is called a broad band measurement, as opposed to narrow band or FFT measurement where energy in narrow energy bands is measured.

Bump Test

Response test where the broad frequency range produced by an impact is used as the stimulus. Sometimes referred to as an impact test.

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Calibration

A test to verify the accuracy of measurement instruments. For vibration, a transducer is subjected to a known motion, usually on a shaker table, and the output readings are verified or adjusted.

Campbell Diagram

A mathematically-constructed diagram used to check for coincidences of vibration sources (1x, 2x, etc. shaft speed) with rotor natural frequencies. The form of the diagram is a rectangular plot of resonant frequency (y-axis) vs. excitation frequency (x-axis). Sometimes called an interference diagram.

Cavitation

A localized low-pressure vaporization condition (cavities or bubbles) within a liquid, as around a propeller or within a pipe or in a pump's suction line. Bubble collapse creates unwanted sound and/or vibration. May be destructive.

Centre Frequency

For a band-pass filter, the centre of the transmission band.

Channel

A sensor (or pickup or transducer) with its associated signal conditioner and monitor (for observing the signal) and recorder (for storing the signal).

Charge Amplifier

Amplifier used to convert accelerometer output impedance from high to low, making calibration much less dependent on cable capacitance.

Coherence

The ratio of coherent output power between channels in a dual-channel Dynamic Signal Analyzer. An effective means of determining the similarity of vibration at two locations, giving insight into the possibility of cause and effect relationships.

Complete Machine

A complete machine is defined as the entire assembly of components, sub-components, and structure, which is purchased to perform a specific task(s). On a Complete Machine Assembly with all individual components operating in their normal operating condition, mode, and sequence, the Component Vibration Level Limits for the complete machine acceptance are the same as when the component is tested individually.

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Condition Monitoring

The measurement, recording and analysis of machinery parameters (such as acceleration) to predict machinery health. Current condition is compared with earlier condition in order to determine if problems are developing. Also called machinery health monitoring.

Constant Bandwidth Filter

A band-pass filter whose bandwidth is independent of centre frequency. The filters simulated digitally in a Dynamic Signal Analyzer are constant bandwidth.

Constant Percentage Filter

A bandpass filter whose bandwidth is a constant percentage of centre frequency such as a 1/3 octave filter. These may be synthesized in Dynamic Signal Analyzers.

Critical Damping

The smallest amount of damping required to return the system to its equilibrium position without oscillation.

Crest Factor

The crest factor is the ratio of peak value to the RMS value. This parameter is used as a trending value to alert when a vibration signal has many "peaks" or "spikes", as may be the case when bearings begin to fail.

Critical Frequency

A particular resonant frequency (see resonance) at which damage or degradation in performance is likely.

Critical Machinery

Machines which are critical to a major part of the plant process. These machines usually do not have spares.

Critical Speed

The speed of a rotating system corresponding to a system resonance frequency.

Critical Speed Map

A rectangular plot of system natural frequency (y-axis) versus bearing or support stiffness (x-axis).

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Cross Axis Sensitivity

A measure of off-axis response of velocity and acceleration transducers.

Crossover Frequency

In sinusoidal vibration testing, the unique forcing frequency at which the required displacement yields the desired acceleration and vice versa.

Cycle

One complete period of a periodic wave form is called a cycle. The units for frequency use to be called "cycles per second" until the ISO standardized on the term "hertz", in honor of Heinrich Hertz, the noted German scientist who was an early investigator of radio wave transmissions.

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Damping

The quality of a mechanical system that restrains the amplitude of motion with each successive cycle. Damping of shaft motion is provided by oil in bearings, seals, etc. The damping process converts mechanical energy to other forms, usually heat.

Decade

The interval between two frequencies which differ by a ratio of exactly 10:1.

Decibel (dB)

A logarithmic measure of a power ratio, according to the following equation:

$$dB = 10 \log \frac{P_1}{P_2} = 20 \log \frac{V_1}{V_2}$$

Because we are seldom able to measure power directly, we generally use the second form of the equation, where the multiplier of 20 implies that power is proportional to the square of the voltage. In the case of vibration signals, it is true that power is proportional to acceleration or velocity squared, so we can express vibration ratios in dB according to:

$$AdB = 10 \log \frac{A_1^2}{A_2^2} = 20 \log \frac{A_1}{A_2}$$

$$VdB = 10 \log \frac{V_1^2}{V_2^2} = 20 \log \frac{V_1}{V_2}$$

where A = acceleration and V = velocity

It is convenient to express vibration levels in terms of dB, so we replace the denominators in the above equations with reference levels which correspond to zero dB:

$$AdB = 20 \log \frac{A}{3.861 \times 10^{-4}}$$

$$VdB = 20 \log \frac{V}{5.568 \times 10^{-4}}$$

where the acceleration reference is 3.861×10^{-4} inches per second squared (RMS), and the velocity reference is 5.568×10^{-7} inches per second (peak).

With these very small reference values, we are assured of always measuring positive dB levels of vibration.

A 6 dB change represents a two-fold change in vibration level, and a 20 dB change represents a ten-fold change in level.

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Degrees of Freedom

A phrase used in mechanical vibration to describe the complexity of the system. The number of degrees of freedom is the number of independent variables describing the state of a vibrating system. For example, a platform experiencing heave, fore-and-aft, left-and-right motions as well as roll, pitch and yaw, is said to have six degrees of freedom. In random vibration measurement, twice the number of averages being used.

Demodulation

Demodulation is used to give an indication of the extent of bearing wear. The main purpose is to remove the dominant low frequency peaks from the signal to highlight any bearing-related peaks. The vibration signal is put through a high pass filter, rectified, and then put through a low pass filter (such as an anti-alias filter). Demodulation is also known as "enveloping".

Digital Filter

A filter that acts on data after it has been sampled and digitized. Often used in Dynamic Signal Analyzers to provide anti-aliasing protection after internal re-sampling.

Differentiation

Representation in terms of time rate of change. For example, differentiating velocity yields acceleration. In a Dynamic Signal Analyzer, differentiation is performed by multiplication by w, where w is frequency multiplied by 2p. (Differentiation can also be used to convert displacement to velocity.)

Digital Signal Processor (DSP)

A microprocessor optimized for digital signal manipulations.

Discrete Fourier Transform

A procedure for calculating discrete frequency components (filters or lines) from sampled time data. Since the frequency domain result is complex (i.e., real and imaginary components), the number of points is equal to half the number of samples.

Displacement

In machinery vibration, the displacement is the actual distance the vibration causes the part in question to move. It is oscillatory and is measured in thousandths of an inch (mils) in the English system and in millimeters (mm) in the SI system. By popular convention, displacement measurements are made in peak-to-peak units.

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Distortion

In mechanics, any unwanted motion. If sinusoidal motion were desired at a fundamental frequency, distortion is any motion at harmonics or subharmonics of that frequency, or any mechanical "hash" (perhaps due to parts colliding). In electronic measurements, distortion is any unwanted signal; for examples amplifiers may generate unwanted signals.

Dynamic Mass

To determine if the mass of the transducer is effecting the measurement, perform the following steps:

a. Make the desired measurement with the accelerometer.

b. Place a mass equivalent to the mass of the accelerometer adjacent to the measuring accelerometer.

c. Repeat the measurement.

d. Compare data from a. and c.

e. If any differences (i.e. shift in frequencies) between a. and c. exist, then a less massive transducer should be used.

Dynamic Motion

Vibratory motion of a rotor system caused by mechanisms that are active only when the rotor is turning at speeds above slow roll speed.

Dynamic Range

The difference between the highest measurable signal level and the lowest measurable signal level that is detectable for a given Amplitude Range setting. Dynamic Range is usually expressed in decibels, typically 60 to 90 dB for modern instruments.

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Eccentricity, Mechanical

The variation of the outer diameter of a shaft surface when referenced to the true geometric centerline of the shaft. Out-of-roundness.

Eccentricity Ratio

The vector difference between the bearing centerline and the average steady-state journal centreline.

Eddy Current

Electrical current generated (and dissipated) in a conductive material (often a rotor shaft) when it intercepts the electromagnetic field of a displacement or proximity probe.

Engineering Units, EU

The units in which a measurement is made; for example velocity may be expressed in millimeters per second, miles per hour, or furlongs per fortnight, depending on the use the data will be put to. Modern instrumentation, such as FFT analyzers allow you to specify what the engineering units are and to apply conversion factors if needed.

Enveloping

See "Demodulation".

Envelopes

Envelopes are a standard method for establishing alarm limits on a reference spectrum. For a particular measurement point, bands are defined along the frequency range (usually about six), particularly around frequencies of interest (for example around 1X and 2X), and alarm limits set for each of these bands. Envelopes are also known as band alarms.

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Fast Fourier Transform, FFT

The Fast Fourier Transform (FFT) is an algorithm, or digital calculation routine used in the FFT analyzer, which calculates a spectrum from a time wave form. In other words it converts, or "transforms" a signal from the time domain into the frequency domain.

FFT Analyzer

Vibration analyzer that uses the Fast Fourier Transform to display vibration frequency components.

Field Balancing

The process of balancing a rotor in its own bearings and supporting structure rather than in a balancing machine.

Filter

An electronic device to pass (pass band) or reject (stop band) a specific frequency band. Classified as low-pass (high-stop), high-pass (low-stop), band-pass or band-stop.

Flat Top Window

As are all windows, the flat top window is used to deal with leakage. The flat top window gives good amplitude accuracy, but has limited frequency resolution.

See also "Leakage" and "Window"

Flexible Rotor

A rotor that deforms significantly at running speed. This term is used for rotors that operate close to or above their first critical speed. A rotor is considered flexible when its speed is more than 75% of its lowest natural frequency in bending.

FMAX

Maximum Frequency Limit of the spectrum being evaluated.

Finite Element Modeling or Finite Element Analysis (FEA)

A computer-aided design technique for predicting the dynamic behavior of a possible future mechanical system.

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First Order Vibration or 1X Vibration

Rotating machine vibration caused by shaft unbalance. Frequency in hertz (Hz) is calculated by shaft RPM/60.

FMIN

Minimum Frequency Limit of the spectrum being evaluated.

Forced Vibration

The oscillation of a system under the action of a forcing function. Typically forced vibration occurs at the frequency of the exciting force.

Forcing Frequency

In a rotating machine, the moving parts impart vibratory forces into the structure, and these forces occur at specific frequencies determined by the dynamics of the moving element. The resulting vibration of the machine will occur at these frequencies and other frequencies that are related to them. The most important forcing frequencies of interest to the maintenance engineer and vibration analyst are the ones related to various faults such as bearing problems, misalignment, mechanical looseness, and so on. These frequencies should be identified and kept at hand by the analyst when examining vibration spectra. One of the most important uses of the VTAG is the listing of the forcing functions present in each machine.

Fourier

Mathematician Baron Jean Baptiste Joseph Fourier (1768-1830) was honored in the term Fast Fourier Transform or FFT.

Free Vibration

Vibration of a mechanical system following an initial force - typically at one or more natural frequencies.

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Frequency

Frequency is the reciprocal of time. If an event is periodic in time, if it repeats at a fixed time interval, then its frequency is one divided by the time interval. If a vibrating element takes one tenth of a second to complete one cycle and return to its starting point, then its frequency is defined to be 10 cycles per second, or 10 hertz (Hz). Although SI standard unit of frequency is the Hz, when analyzing machinery vibration we often find it more convenient to express frequency in cycles per minute (cpm), which corresponds to revolutions per minute (rpm). Frequency in rpm is simply frequency in Hz times 60. Another common frequency representation used in machinery monitoring is multiples of turning speed, or "orders". Frequency in orders is frequency in rpm divided by the turning speed of the machine. The second order is then the second harmonic of turning speed, and so on. This is especially convenient if the machine is varying in speed, for the frequency representation on a spectrum will be the same regardless of speed. Two machine spectra can therefore more easily be compared if they are both expressed in orders. Conversion of the frequency axis of a spectrum to orders is called "order normalization", and is done by the monitoring software.

Frequency Domain

Presentation of a signal whose amplitude is measured on the Y-axis, and the frequency is measured on the X-axis.

Frequency Range

The difference in frequency between the upper and lower cutoff frequencies of a measurement: FMAX – FMIN.

Frequency Resolution

The frequency resolution is the minimum spacing between data points in the spectrum.

$$\textbf{Resolution} = \frac{\textbf{FMAX—FMIN}}{\textbf{Number of Lines of Resolution}}$$

FMAX = Maximum Frequency Limit of the spectrum being evaluated.

FMIN = Minimum Frequency Limit of the spectrum being evaluated.

Frequency Response

The amplitude and phase response characteristics of a system.

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Fundamental Frequency

The spectrum of a periodic signal will consist of a fundamental component at the reciprocal of the period and a series of harmonics of this frequency. The fundamental is also called the "first harmonic". It is possible to have a periodic signal where the fundamental is so low in level that it cannot be seen, but the harmonics will still be spaced apart by the fundamental frequency.

Fundamental Mode of Vibration

That mode having the lowest natural frequency

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G

The value of acceleration produced by the force of gravity. 1g = 9.80665m/s^2 = 980.665 cm/s^2 = 386.089 in/s^2 = 32.174 ft/s2

Gear Mesh Frequency

A potential vibration frequency on any machine that contains gears; equal to the number of teeth multiplied by the rotational frequency of the gear.

Gear mesh = Number of teeth x Shaft speed

g Units or Gravitational Units

A way to express acceleration, in terms of a ratio. Divide a given acceleration by the appropriate value (9.80665 m/s2 or 386.087 in/sec^2 or 32.1739 ft/sec^2).

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Hamming Window

Hamming windows are rarely used now. A Hamming window is similar to a Hanning window, but the amplitude is not reduced to zero at each end of the time signature. (The Hanning window forces the amplitude at the start and end of the time signature to zero.) Hanning and Hamming provide better frequency resolution than Flat Top, however Flat Top provides better amplitude accuracy. See also "Leakage" and "Window".

Hanning Window

An FFT window function that provides better frequency resolution than the flat top window, but with reduced amplitude accuracy. The Hanning window forces the amplitude at the start and end of the time signature to zero. The Hanning window is the most popular window used in vibration data collection. See also "Leakage" and "Window.

Harmonics

Harmonics, also called a harmonic series, are components of a spectrum which are integral multiples of a fundamental frequency. A harmonic series in a spectrum is the result of a periodic signal in the wave form. Harmonic series are very common in spectra of machinery vibration.

Heavy Spot

The angular location of the imbalance vector at a specific lateral location on a shaft. The heavy spot typically does not change with rotational speed.

Hertz (Hz)

The unit of frequency in the SI measurement system is the hertz, abbreviated Hz. One hertz is equal to one cycle per second. The name is in honor of Heinrich Hertz, an early German investigator of radio wave transmission.

High Spot

The angular location on the shaft directly under the vibration transducer at the point of closest proximity. The high spot can move with changes in shaft dynamics (e.g., from changes in speed).

High-Pass Filter

A device that separates the components of a signal and allows only those components above a selected frequency to be amplified.

Hysteresis

Non-uniqueness in the relationship between two variables as a parameter increases or decreases. Also called dead-band, or that portion of a system's response where a change in input does not produce a change in output.

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Imbalance

A condition of a rotating part where the center of mass does not lie on the center of rotation. Imbalance of a rotor causes a centripetal force at the frequency of the rotation rate to be applied to the bearings. If it is large, it can severely shorten the life of the bearings, besides causing undue vibration of the machine. Forces caused by imbalance are proportional to the square of the RPM, and this means that high speed machines must be balanced to a higher standard than low speed machines.

Imbalance exists in several forms:

Static Imbalance is the condition where the principal inertia axis of a rotor is offset from and parallel to the axis of rotation. A rotor with static imbalance will seek a position with the heavy spot at the bottom if placed on level knife edges. Static imbalance can be corrected by the addition of a single correction mass.

Couple Imbalance is the condition where the principal inertia axis intersects the rotation axis of the rotor at the center of gravity. A rotor with couple imbalance will be stable in any position on knife edges, but will produce out-of-phase imbalance forces on the bearings when rotated. Correction of couple imbalance requires the addition of two correction masses.

Dynamic Imbalance is a combination of these two types, and is the most common type found in practice. In dynamic imbalance, the principal inertia axis neither intersects nor is parallel to the axis of rotation. Correction of dynamic imbalance requires at least two correction masses.

Impact Test

Response test where the broad frequency range produced by an impact is used as the stimulus. Sometimes referred to as a bump test.

Impedance, Mechanical

The mechanical properties of a machine system (mass, stiffness, damping) that determine the response to periodic forcing functions.

Impulse

The integral of force over a time interval.

Influence Coefficients

Mathematical coefficients that describe the influence of system loading on system deflection.

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Integration

A process producing a result that, when differentiated, yields the original quantity. Integration of acceleration, for example, yields velocity. Integration is also used to convert velocity to displacement.

Integrator

Electronic cCircuitry which converts an acceleration signal to a velocity signal or a velocity signal to a displacement signal.

Isolation

A reduction in motion severity, usually by a resilient support. A shock mount or isolator attenuates shock. A vibration mount or isolator attenuates steady-state vibration.

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J

Jerk

The rate of change of acceleration with time.

Journal

Specific portions of the shaft surface from which rotor applied loads are transmitted to bearing supports.

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Key-Phasor

A signal used in rotating machinery measurements, generated by a transducer observing a once-per-revolution event. The key-phasor signal is used in phase measurements for analysis and balancing. (Key-phasor is a Bentley Nevada trade name.)

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Leakage

An unfortunate result of sampling with finite intervals. When time data is collected, the length of time record will not correspond to a discrete number of cycles. Each sample will start at a different stage in the cycle. In order to process this data, the analyzer combines all the time samples into one long record for processing. This means that there will be a jump in the amplitude where two samples meet. This appears in the spectrum as a broadening of the peaks known as "leakage".

In order to combat this problem, analyzers apply one of a number of "windows" to reduce the effect of this inconsistency in the time domain data. Common window types used in vibration data collection are Hanning, Flat Top, Hamming, Rectangular and Uniform. Hanning is most commonly used by vibration data collectors.

See also "Window" and "Hanning".

Line Amplitude Limit

The maximum amplitude of any line of resolution contained within a band shall not exceed the Line Amplitude Acceptance Limit for the Band.

Linearity

The closeness of a calibration curve to a specified straight line, preferably passing through zero. Commonly specified as a % of full scale.

Linear Non-Overlapping Average

An averaging process where each Time block sample used in the averaging process contains data not contained in other Time blocks (i.e. non-overlapping) used in the averaging. Linear averaging is performed in the Frequency Domain, and each sample is weighted equally.

Linear System

A system is linear if its magnitude of response is directly proportional to its magnitude of excitation, for every part of the system.

Line of Resolution

A single data point from a spectrum, which contains vibration amplitude information. The Line of Resolution amplitude is the Band Overall Amplitude of the frequencies contained in the Frequency Resolution.

Lines

The total number of data points in a spectrum (e.g. 400, 800, 1600, etc.). See also BIN

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Machine Running Speed

The **NOMINAL SPEED** is is the approximate running speed of the machine entered when the machine is set up in the host software, or when an off route test is set up. The **ACTUAL RPM** is the actual running speed of the machine when each measurement is collected. An off route test can be defined to use a tachometer input to determine the actual running speed of the machine.

Mean

A value halfway between the maximum and minimum values of the parameter under consideration.

Mean-Time-Between-Failure

The time during which all parts of the machine perform within their specified limits, under a standard set of criteria and conditions.

Mean-Time-To-Failure

The total time the items have performed divided by the total number of failures within that population, under a standard set of criteria and conditions. This is an indication of the reliability of machines that cannot be repaired.

Measurement Point

Location on a machine/component at which vibration measurements are made.

Mechanical Impedance

The ratio of force to velocity, where the velocity is a result of that force only. Its reciprocal is "mobility"..

Micrometer (Micron)

One-millionth (0.000001) of a meter: 1 micron = 1 x E-6 meters = 0.04 mils

Mil

One thousandth (0.001) of an inch: 1 mil = 25.4 microns

Modal Analysis

The process of breaking complex structural motion into individual vibration modes. Resembles frequency domain analysis that breaks complex vibration down to component frequencies.

Mode

A characteristic pattern in a vibrating system. All points reach their maximum displacements at the same instant.

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Narrow Band Analysis

Narrow band analysis is another name for FFT Analysis.

Natural Frequency

The frequency of free vibration of a system when excited with an impact force. (Bump Test).

Noise

The total of all interferences in a measurement system, independent of the presence of signal.

Nominal Speed

The nominal speed is the estimated machine running speed entered when defining a machine.

Nonlinearity

The deviation from a best fit straight line of true output vs. actual value being measured.

Normalization

With regard to vibration spectra of rotating machines, normalization is the process of dividing the frequency values along the x axis by the turning speed of the machine. After this is done, the machine speed will appear at a frequency of 1, the second harmonic will be at a frequency of 2, and so on.

Nyquist Criterion

Requirement that a sampled system sample at a frequency greater than twice the highest frequency to be measured.

Nyquist Plot

A plot of real versus imaginary spectral components that is often used in servo analysis. This should not be confused with a polar plot of amplitude and phase of 1x vibration.

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Octave

The interval between two frequencies with a ratio of 2 to 1.

Oil Whirl/Whip

An unstable free vibration whereby a fluid-film bearing has insufficient unit loading. Under this condition, the shaft centreline dynamic motion is usually circular in the direction of rotation. Oil whirl occurs at the oil flow velocity within the bearing, usually 40 to 49% of shaft speed. Oil whip occurs when the whirl frequency coincide with (and becomes locked to) a shaft resonant frequency. (Oil whirl and whip can occur in any case where fluid is between two cylindrical surfaces.)

Orbit

The path of the shaft centreline motion during rotation. The orbit is observed with an oscilloscope connected to x and y-axis displacement transducers. Some dual-channel Dynamic Signal Analyzers also have the ability to display orbits.

Orders

In rotating machines, orders are multiples or harmonics of the turning speed. In comparing vibration spectra of rotating machines, it is convenient to express the frequency axis of the spectra in orders, especially if the machine speed varies between measurements.

Order Analysis

Order analysis is simply frequency analysis where the frequency axis of the spectrum is expressed in orders of rpm rather than in Hz or cpm.

Order Tracking

Control of a computer's data sampling rate, such that display of vibrations at multiples of the shaft's rotating speed 1X, 2X, 3X etc.) are enhanced and more easily identified and measured.

Orthogonal

Orthogonal refers to independent dimensions of a measured quantity. For instance, on a map, it is possible to locate a point by its longitude and latitude. These two measures are independent of each other, and both are required to locate the point. They are said to be orthogonal. In vibration measurement for machine monitoring, we measure acceleration in three orthogonal directions, and from these three measurements, the actual orientation in space of the vibration can be determined. In three dimensional space, orthogonal directions are 90 degrees from each other.

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Oscillation

Variation with time of a quantity such as force, stress, pressure, displacement, velocity, acceleration or jerk. Usually implies some regularity (as in sinusoidal or complex vibration).

Oscillator-Demodulator

A signal conditioning device that sends a radio frequency signal to an eddy-current displacement probe, demodulates the probe output, and provides output signals proportional to both the average and dynamic gap distances. (Also referred to as Proximitor - a Bentley Nevada trade name.)

Overall Level

The overall level of vibration of a machine is a measure of the total vibration amplitude over a wide range of frequencies, and can be expressed in acceleration, velocity, or displacement. The overall level can be measured with an analog vibration meter, or it can be calculated from the vibration spectrum by summing up all the amplitude values over a frequency range.

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Peak

The peak value of a signal is the maximum excursion in one direction from the zero point. The actual value can be displacement, velocity, or acceleration, or could simply be expressed as a voltage.

In a spectrum, a peak is simply a sharp maximum.

Peak Hold

In a Dynamic Signal Analyzer, a type of averaging that holds the peak signal level for each frequency component.

Peak-to-Peak (Pk-Pk) Value

In measuring the level of a signal wave form, the peak-to-peak value is the difference between the highest positive peak level and the lowest negative peak value. In machine vibration, displacement is generally measured in peak-to-peak units.

Period

The amount of time, usually expressed in seconds or minutes, required to complete one cycle of motion of a vibrating machine or machine part. The reciprocal of the period is the frequency of vibration.

Periodic

A signal is periodic if it repeats the same pattern over time. The spectrum of a periodic signal is always a series of harmonics.

Phase

Phase is a relative time difference between two signals. It is usually measured in units of angle rather than units of time, and it makes sense only if the two signals being compared are of the same frequency. One cycle of a periodic signal represents a complete circle, or 360 degrees of phase angle. Phase measurement is a two-channel measurement, and has no meaning when considering a single signal. In balancing or rotating equipment, phase measurement relative to shaft position is of vital importance, and a tachometer pulse derived from a position on the shaft is used as a reference for zero phase angle. Phase is also an important part of the frequency response measurement.

Phase Reference Probe

A device for giving a once-per-shaft-revolution signal.

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P

Pickup

"Pickup" is instrumentation people's slang for a vibration transducer. It is not specific for any particular type.

Piezoelectric

Any material which provides a conversion between mechanical and electrical energy. For a piezoelectric crystal, if mechanical stresses are applied on two opposite faces, electrical charges appear on some other pair of faces.

Piezoelectric Transducer

A transducer which depends upon deformation of its sensitive crystal or ceramic element to generate electrical charge and voltage.

Piezoresistive Transducer

One whose electrical output depends upon deformation of its semiconductor resistive element, offering greater resistance change than does the wire of a strain-gage transducer, for a given deformation.

Pitch

Rotation in the plane of forward motion, about the left-right axis. In music, relates to frequency.

Polar Plot

Polar co-ordinate representation of the locus of the 1x vector at a specific lateral shaft location with the shaft rotational speed as a parameter.

Power Spectrum

An auto spectrum or power spectrum displays magnitude which represents the power at each frequency. Phase is ignored. R.M.S averaging produces an auto spectrum.

Power Spectral Density

Describes the power of random vibration intensity, in mean-square acceleration per frequency unit, as g2/Hz or m2/s3. Compare with auto spectral density.

Precision

The smallest distinguishable increment (resolution); represents a measurement system's possible or design performance.

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Preload, Bearing

The dimensionless quantity that is typically expressed as a number from zero to one where a preload of zero indicates no bearing load upon the shaft, and one indicates the maximum preload (i.e., line contact between shaft and bearing).

Preload, External

Any of several mechanisms that can externally load a bearing. This includes 'soft' preloads such as process fluids or gravitational forces as well as "hard" preloads from gear contact forces, misalignment, rubs, etc.

Probability Distribution

A statistical term to represent the probability of an event. The most common is a "bell shaped" graph of percentage vertical vs. value horizontal, with most options clustered around the mean value.

Probe

A machinery-mounted sensor (usually internal).

Proximity Sensor

Usually a displacement sensor for measuring the varying distance between a housing and a rotating shaft.

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Radial

Radial means in a direction toward the center of rotation of a shaft or rotor. In machine vibration measurements, radial measurements are made with the transducer oriented so its sensitive axis is in the radial direction. Radial measurements are best for detecting imbalance in rotors.

Rectangular Window

A windowing function with uniform weighting across the time record. This window does not protect against leakage, and should be used only with transient signals contained completely within the time record. The same as Uniform Window. See also "Leakage" and "Window.

Repeatability

The ability of a transducer or instrument to reproduce readings taken under the same conditions repeatedly. Do not confuse with accuracy.

Resonance

The condition of vibration amplitude and phase change response caused by corresponding system sensitivity to a particular forcing frequency. A substantial amplitude increase and related phase shift typically identify a resonance.

Resolution

The smallest change in input that will produce a detectable change in an instrument's output.

Rigid Rotor

A rotor that does not deform significantly at running speed. A rotor, whose parts do not take up motion relative to each other, i.e., all points move in the same direction at the same instant of time. A rotor is considered rigid when its speed is less than 75% of its lowest natural frequency in bending.

Ringing

Continued oscillation after an external force or excitation is removed, as when a guitar string is plucked.

Rolling Element Bearing

A bearing whose low friction qualities derive from rolling elements (balls or rollers) that require little lubrication.

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Root Cause Analysis

Determining what actually caused a failure, as opposed to what appears to have been the cause. Usually requires the services of a specialized failure analysis lab.

Root Mean Square (RMS)

RMS stands for Root Mean Square, and is a measure of the level of a signal. It is calculated by squaring the instantaneous value of the signal, averaging the squared values over time, and taking the square root of the average value. The RMS value is the value which is used to calculate the energy or power in a signal. The RMS value of a sine wave is .707 times the peak value, but the RMS value of a complex signal is difficult to predict without measuring it. It is the accepted convention to measure the RMS value of acceleration when performing vibration analysis of machines.

Rotational Speed

The number of times an object completes one complete revolution per unit of time, e.g., 1800 RPM.

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Sampling Rate

The number of readings an A/D converter takes per second or per minute.

Seismic

Refers to a sensor that depends upon the inertia of an internal mass to generate a signal, as an accelerometer or velocity pickup.

Sensitivity

The ratio between electrical signal (output) and mechanical quantity (input) in a mechanical-to-electrical transducer.

Sensor

Another name for a transducer.

Shaker

A device which produces controlled and reproducible mechanical vibration for the vibration testing of mechanical systems, components and structures.

Shock Pulse

A transmission of kinetic energy into a system in a relatively short interval compared with the system's natural period. A natural decay of oscillatory motion follows. Usually displayed as time history, as on an oscilloscope.

Sidebands

Sidebands are spectral components which are the result of amplitude or frequency modulation. The frequency spacing of the sidebands is equal to the modulating frequency, and this fact is used in diagnosing machine problems by examining sideband families in the vibration spectrum. For instance, a defective gear will exhibit sidebands at the gear rpm around the gearmesh frequency.

Signal

In vibration analysis, a signal is an electric voltage or current which is an analog of the vibration being measured. The signal is usually meant to be the desired part of the quantity, and the accompanying undesired part is called the noise. The signal to noise ratio is an important parameter in any measurement system.

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Signal Conditioner

An amplifier following a sensor, which prepares the signal for succeeding amplifiers, transmitters, readout instruments, etc. May also supply sensor power.

Signature (Spectrum)

Term usually applied to the vibration frequency spectrum which is distinctive and special to a machine or component, system or subsystem at a specific point in time, under specific machine operating conditions, etc. Usually presented as a plot of vibration amplitude (displacement, velocity or acceleration) versus time or versus frequency. When the amplitude is plotted against time it is usually referred to as the **time waveform**.

Simple Harmonic Motion

Simple harmonic motion is the simplest possible motion of a vibrating system, and it consists of a single frequency at constant amplitude. An example of simple harmonic motion is a mass oscillating up and down on a spring. The wave form of simple harmonic motion is the sine wave. A single degree of freedom mechanical system would exhibit simple harmonic motion.

Sine Wave

A sine wave, also called a sinusoid, is the graph of the mathematical sine function from trigonometry. It consists of a single frequency at constant amplitude. A mechanical system of one degree of freedom would vibrate with a sinusoidal wave form, but this is never found in the real world.

Ski Slope

If the accelerometer is either mechanically loose on the block, has a loose wire, is overheated or experiencing a temperature transient, or physically overloaded when data is collected, the problem will manifest itself in the spectrum as a low frequency "ski slope" at the left end of the low frequency range graph.

Soft Foot

A condition that exists when the bottoms of all of the feet of a machine are not in the same plane (can be compared to a chair with one short leg). Softfoot is present if the machine frame distorts when a foot bolt is loosened or tightened. It must be corrected before the machine is actually aligned.

Sound Intensity

In a specified direction, the average rate of sound energy flow through a unit area perpendicular to that direction.

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Spall

A flake or chip of metal, removed from one of the races of a rolling-element bearing. That bearing is nearing the end of its useful life.

Spectra

Spectra is the plural of spectrum.

Spectral Map

A three-dimensional plot of the vibration amplitude spectrum versus another variable, usually time or rpm. Also known as a Waterfall Plot.

Spectral Point

A spectral point is a point on a machine at which a vibration spectrum will be collected.

Spectrum

The spectrum is the result of transforming a signal from the time domain to the frequency domain. It is the decomposition of a time signal into a collection of sine waves. The plural of spectrum is spectra. Spectrum analysis is the procedure of doing the transformation, and it is most commonly done with an FFT analyzer.

Spectrum Analyzer

An instrument which displays the frequency spectrum of an input signal.

Standard Deviation

A statistical term: the square root of the mean of the squares of the measured deviations from the mean value.

Steady State Vibration

Periodic vibration for which the statistical measurement properties (such as the peak, average, RMS and mean values) are constant.

Stiffness

The spring-like quality of mechanical and hydraulic elements to elastically deform under load: the ratio of force (or torque) to deflection.

Strain

The physical deformation, deflection, or change in length resulting from stresses (force per unit area).

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Strain-Gage Transducer

A changing-resistance sensor whose signal depends upon sensitive element deformation. In an unbonded wire strain-gage accelerometer, inertia affects a mass supported by nichrome wires; the wires change resistance in proportion to acceleration. The term may include piezoresistive accelerometers.

Sub-Harmonic

Sinusoidal quantity of a frequency that is an integral sub-multiple of a fundamental frequency

Sub-Synchronous

Component(s) of a vibration signal which has a frequency less than shaft rotation frequency.

Swept-Sine Testing

Sine shaking whose frequency is smoothly and continuously varied. Commonly required for sequentially identifying resonances.

Synchronous

Synchronous literally means "at the same time", but in the spectrum analysis, synchronous components are defined as spectral components which are integer multiples, or harmonics, of a fundamental frequency. They may in some cases exist as multiples of an integral fraction of the fundamental frequency, in which case they are called sub harmonics.

Synchronous Sampling

In a Dynamic Signal Analyzer, it refers to the control of the effective sampling rate of data; which includes the processes of external sampling and computed re-sampling used in order tracking.

Systeme Internationale (SI)

SI stands for Systeme Internationale, which is the successor to the metric system of weights and measures. The United States is the only industrial country in the world which does not use it.

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Tangential

In measuring triaxial vibration in rotating machines, one of the sensitive axes of the transducer is tangent to the rotating shaft in question. It is perpendicular to the radial transducer, which is a direction toward and away from the center of the shaft. See also Orientation.

Time Averaging

In a Dynamic Signal Analyzer, averaging of time records that result in reduction of asynchronous components.

Time Domain

Vibration is an oscillation in position as function of time, and is said to exist in the time domain. The signal from a transducer is also in the time domain, and when it is displayed on the screen of an oscilloscope, it is called a waveform. Although most diagnostics of machine vibration problems is done via spectrum analysis, some types of information are more easily seen in the waveform; for example when looking at repetitive impacting in a rolling element bearing.

Time Record

In a Dynamic Signal Analyzer, the sampled time data converted to the frequency domain by the FFT. Most Dynamic Signal Analyzers use a time record of 1024 samples.

Torsional Vibration

Amplitude modulation of torque measured in degrees peak - peak referenced to the axis of shaft rotation.

Tracking Filter

A low-pass or band-pass filter which automatically tracks the input signal. A tracking filter is usually required for aliasing protection when data sampling is controlled externally.

Transducer

A transducer is a device which converts one type of energy, such as vibration or sound, into a different type of energy, usually an electric current or voltage. Transducers are at the centre of instrumentation systems, and are usually also the weakest links. They contribute noise to the measured signals and also generate distortion because of non-linearities. They are subject to changes in their sensitivity, and therefore require regular calibration. Some types of transducer are much more reliable and linear than others; an example is the piezoelectric accelerometer, which is by far the best type for general vibration measurement.

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Transient Vibration

Temporarily sustained vibration of a mechanical system. It may consist of forced or free vibration or both. Typically this is associated with changes in machine operating condition such as speed, load, etc.

Transmissibility

In steady-state vibration, transmissibility is the non-dimensional ratio of response motion/input motion: two displacements, two velocities or two accelerations. The maximum transmissibility value is the mechanical "Q" of a system. At resonance, transmissibility is maximum.

Trigger

Any event which can be used as a timing reference. In a Dynamic Signal Analyzer, a trigger can be used to initiate a measurement.

True Peak

The actual maximum amplitude of a complex waveform - must be measured in the Time Domain. Peaks measured in the Frequency Domain represent the amplitudes of the Fourier Series sinewave components that have resulted from the Fourier Transform of the Time Waveform. These sinewave components when added together, by both amplitude and phase, will result in the true Time Waveform.

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U

Unbalance

See Imbalance.

Uniform Window

In a Dynamic Signal Analyzer, a windowing function with uniform weighting across the time record. This window does not protect against leakage, and should be used only with transient signals contained completely within the time record. The same as Rectangular Window.

See also "Leakage" and "Window.

Unit

Every measurement is expressed as a multiple or fraction of some appropriate, well-defined unit quantity such as centimeter, volt, etc.

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VdB

VdB is a decibel representation of vibration level where the reference, or zero dB level, is 10^{-9} meters per second according to the SI system of units. The US Navy does not recognize the SI standard, however, and uses a reference value of 10^{-8} meters per second. This means there is a 20 dB difference in level between measurements made in the two systems, with the Navy dB numbers being 20 dB lower for a given velocity level. Most of the industrial users in the US use the Navy standard.

Vector

A quantity which has both magnitude and direction (phase).

Velocity

Velocity is defined as the time rate change of position, and has units of distance per unit time. In vibration signals, velocity is also the rate of change of displacement, and is expressed usually in inches per second or millimeters per second. Velocity is also the time integral of acceleration, and it is often calculated in practice by integrating acceleration.

Vibration

Vibration is the oscillation of a point, an object, or a part of an object around a fixed reference, or rest, position. An object can vibrate as a unit, in which case it is called "whole body vibration", or, as is usually the case, an object can vibrate in a complex way where it deforms and different parts of it vibrate at different frequencies and amplitudes.

Vibration Meter

An apparatus (usually an electronic amplifier, detector and readout meter) for measuring electrical signals from vibration sensors.

Vibration Signature

The vibration signature of a machine is the characteristic pattern of vibration it generates while it is in operation. The actual signal from a vibration transducer can be considered the signature, but the spectrum of the vibration signal is usually referred to as the signature. It has been said that of all the non-destructive tests than can be made on a machine, the one containing the most information is the vibration signature.

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Waveform

The waveform is the shape of a time domain signal as seen on an oscilloscope screen. It is a visual representation or graph of the instantaneous value of the signal plotted against time. Inspection of the waveform can sometimes reveal information about the signal that the spectrum of the signal does not show. For instance a sharp spike or impulse and a randomly varying continuous signal can have spectra that look almost identical, while their waveforms are completely different. In machine vibration, spikes are usually caused by mechanical impacting, while random noise can be caused by the advanced stages of bearing degradation.

Waterfall Plot

A three-dimensional plot of the vibration amplitude spectrum versus another variable, usually time or rpm. Also known as a Spectral Map.

Window

As a result of the finite nature of the time records, "leakage" occurs which results in smearing of the frequency components. Windows are used to limit the effects of leakage. Hanning, Hamming, Flat top, and Uniform (or Rectangular) are often provided as windowing options, however Hanning is most commonly used for routine data collection. Uniform or Rectangular windowing actually provides no protection against leakage.

Also see "Leakage.

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Zero-to-Peak

N

See peak, as in peak value. Half of the peak-to-peak value.

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Diagnosing Machine Faults

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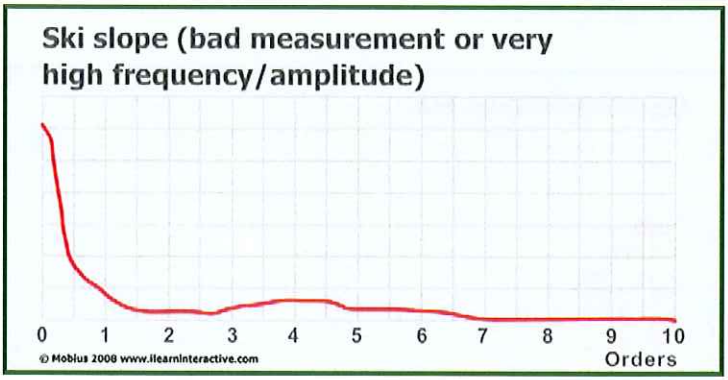
Ski-Slope

Symptoms: High near 0 Hz, decaying down across the spectrum



If you see that the spectrum begins at a high level at the low frequency end of the graph, and slowly decays across the graph, then there has either been a problem with the sensor, or the sensor experienced a shock/transient during the measurement process. The transient may be mechanical (the sensor was bumped, or very high vibration), thermal (the sensor was placed on a very hot or called surface), or electrical.

The spectrum will have a ski-slope and a raised noise-floor at the high frequency end of the spectrum if the transducer becomes "saturated". This typically occurs when there is a source of high vibration at high frequency.

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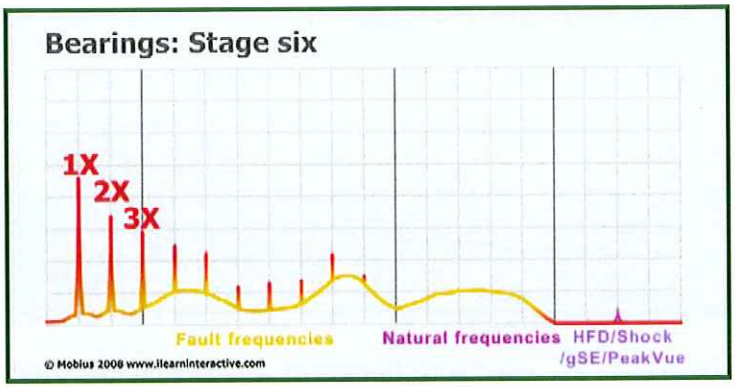
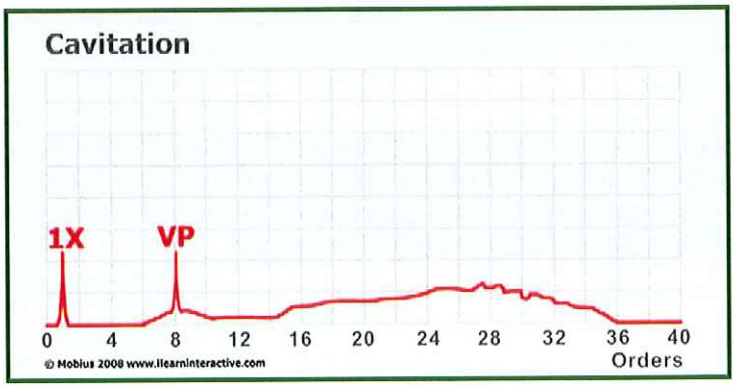
Raised Noise Floor

Symptoms: Bottom of spectrum raised

If the entire noise floor is raised, it is possible that you have extreme bearing wear:



If the noise is biased toward the higher frequencies, then you may have process or flow noise, with cavitation possible:



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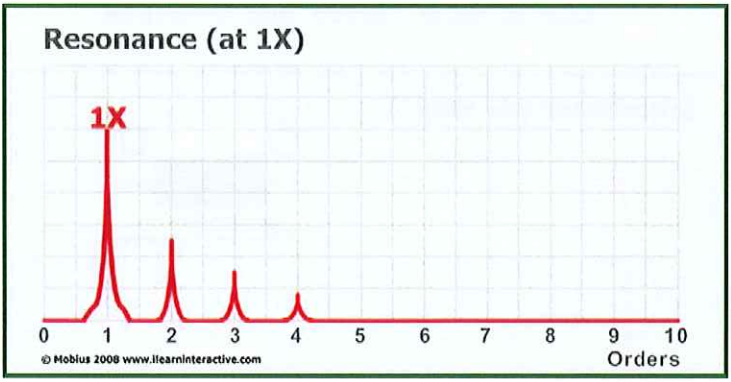
Smaller "humps" may be due to resonances, or closely spaced sidebands. A high resolution measurement (or graphical zoom and a log scale) may reveal whether the source is sidebands or a resonance. If you can change machine speed, the resonant frequency will not move – but the other peaks will. Sidebands will typically be symmetrical around a dominant peak, for example 1X, 2X, 100/120 Hz, etc.



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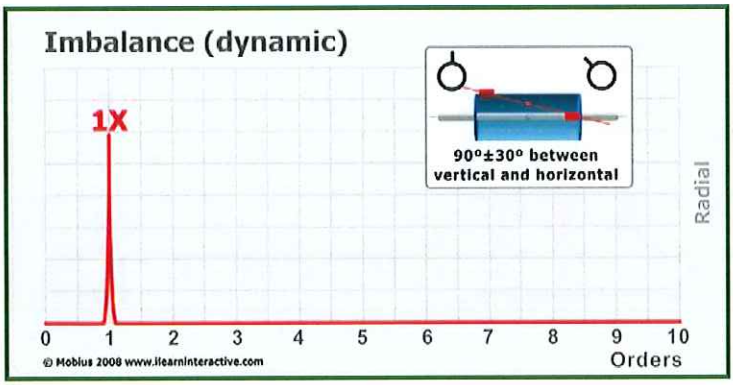
Dynamic Imbalance

Symptoms: 1X radial (V & H)
Levels highest in horizontal axis (due to greatest flexibility).
0-180° phase difference across machine. 90° ±40° between vertical and horizontal.



The technical way to describe unbalance is as a condition where "a shaft's geometric centerline and mass centerline do not coincide", or where "the center of mass does not lie on the axis of rotation". In other words, there is a heavy spot somewhere along the shaft.

Dynamic imbalance is a combination of static and couple imbalance. 1X RPM will dominate, but will be highest in the direction the machine can move most freely – typically in the horizontal axis.

The phase difference from one end of the machine to the other could range between **0** and **180°** out of phase. There will be **90° ±40°** between vertical and horizontal readings. The difference between vertical and horizontal readings taken from each bearing should be approximately equal.

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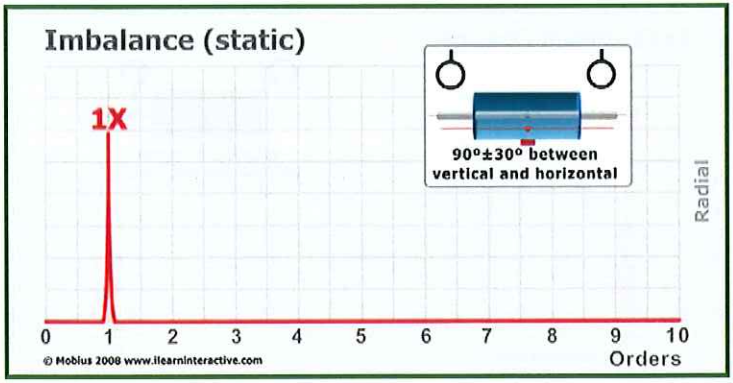
Static Imbalance

Symptoms: 1X radial (V & H)
In phase across machine - 90º ±30º between vertical and horizontal.



If a machine were out of balance we would expect to see a sinusoidal time waveform, with a frequency of the running speed, and a large peak in the spectrum at the running speed (1X).

The simplest type of imbalance is equivalent to a heavy spot at a single point in the rotor. This is called a static imbalance because it will show up even if the rotor is not turning - if placed in frictionless bearings the rotor will turn so the heavy spot is at the lowest position.

Static imbalance results in 1X forces on both bearings of the rotor, and the forces on both bearings are always in the same direction. The vibration signals taken at each end of the machine (in the same direction) are in-phase. There will be **90º ±30º** between readings taken in the vertical and horizontal directions.

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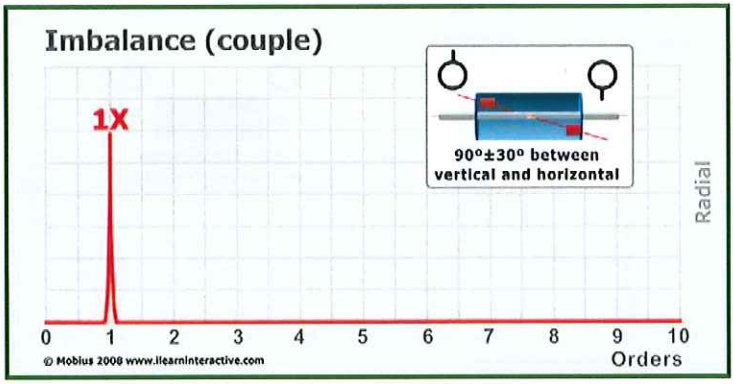
Couple Imbalance

Symptoms: 1X radial (V & H)
Out of phase across machine. 90º ±30º between vertical and horizontal.



If a machine were out of balance we would expect to see a sinusoidal time waveform, with a frequency of the running speed, and a large peak in the spectrum at the running speed (1X).

A rotor with couple imbalance may be statically balanced (it may seem to be perfectly balanced if placed in frictionless bearings). But when rotated, it will produce centrifugal forces on the bearings.

The vibration signals taken at each end of the machine (in the same direction) are **180º** out-of-phase. There will be **90º ±30º** between readings taken in the vertical and horizontal directions.

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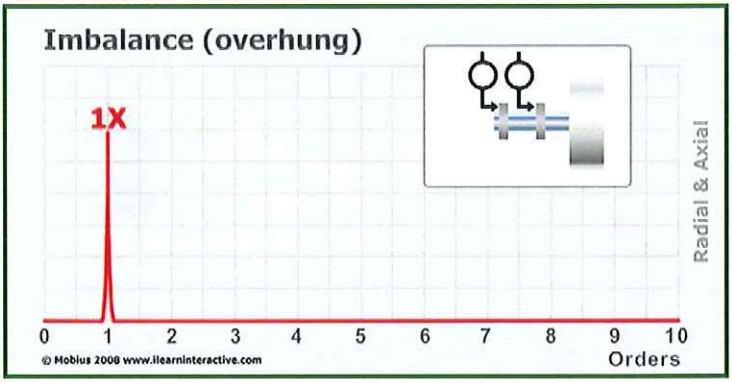
Imbalance: Overhung Machines

Symptoms: High 1X axial, 1X radial (V & H)
Axial phase readings in-phase.



In an overhung or cantilevered machine, you will see a high 1X vibration level in the axial direction, as well as the vertical and horizontal. Measurements in the axial direction will be in-phase. The difference between vertical and horizontal readings taken from each bearing should be approximately equal.

We see the high 1X in axial because the imbalance creates a bending moment on the shaft, causing the bearing housing to move axially. Examples of overhung rotors are close-coupled pumps, axial flow fans, and small turbines.

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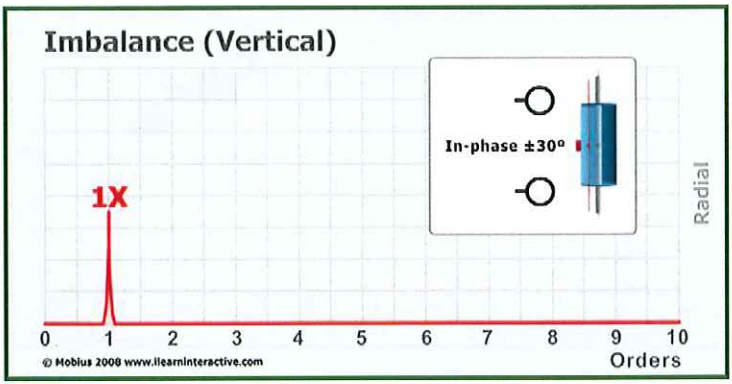
Imbalance: Vertical Machines

Symptoms: 1X radial (horizontal)
Phase readings similar in same direction at different points on machine.



The spectrum again will show a strong 1X peak when measured in the radial direction (horizontal or tangential).

To isolate motor imbalance from pump imbalance, it may be necessary to break the coupling and run the motor solo while measuring 1X. If the 1X level is still high, the problem is the motor; otherwise it is the pump.

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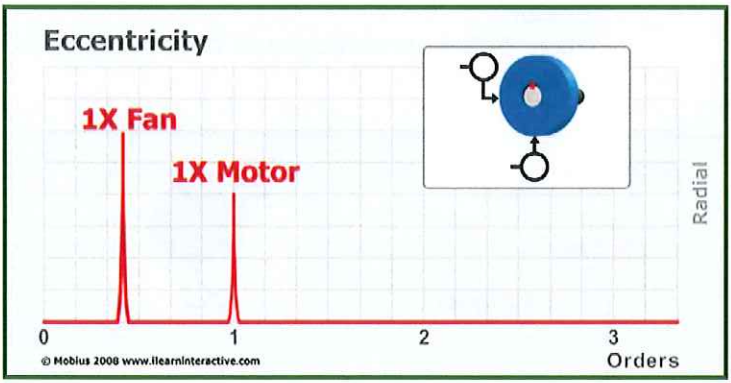
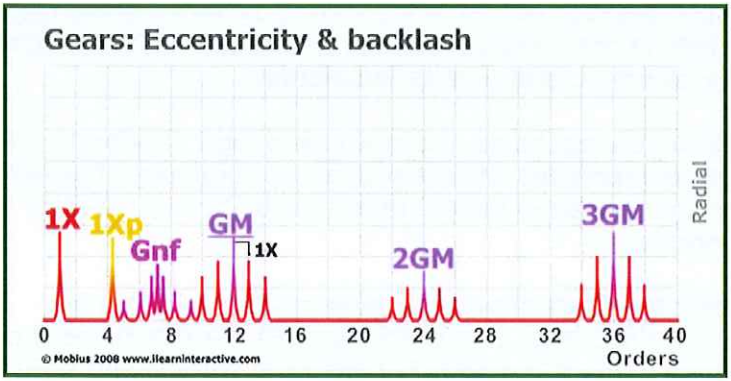
Eccentric Rotor or Gear

Symptoms: 1X radial (V and H)



Eccentricity occurs when the center of rotation is offset from the geometric centerline of a gear, bearing, or rotor.

Eccentric rotors/gears will generate strong 1X radial components, especially in the direction parallel to the rotor/gear. This condition is very common, and mimics imbalance.



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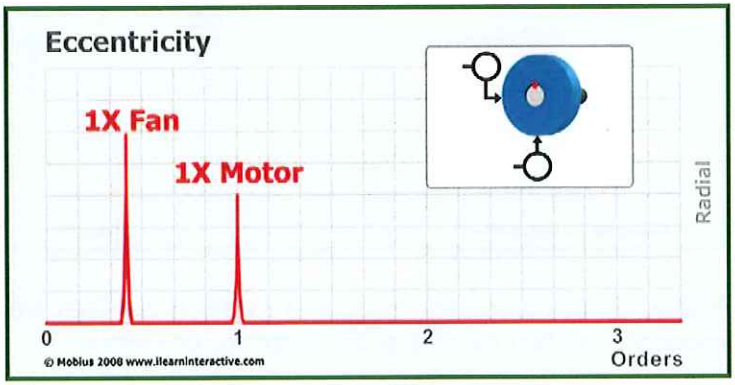
Eccentric Sheaves

Symptoms: 1X radial (V and H)
Levels highest in direction of greatest belt tension.
Phase between vertical and horizontal axis could be 0º or 180º



Eccentricity occurs when the center of rotation is offset from the geometric centerline of a sheave (pulley).

Eccentric sheaves will generate strong 1X radial components, especially in the direction parallel to the belts. This condition is very common, and mimics imbalance.

In belt driven machines, there will be a high 1X vibration level on both components (motor and fan for example), however due to the change in speed, these will be at two different frequencies.

Eccentricity in belt driven machines can be checked by removing the belt(s) and checking again for the 1X peak on the motor. Phase readings between the vertical and horizontal axis could either be **in-phase** or **180º** out of phase.

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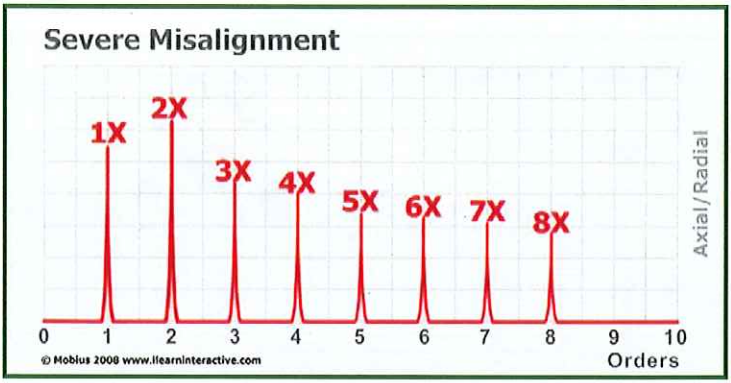
Misalignment

Frequency: 1X and 2X (and 3X and 4X...)
Axial and radial (V & H)



In short, misalignment is a condition where the centerlines of coupled shafts do not coincide.
เกิดขึ้นพร้อมกัน

If the misaligned shaft centerlines are parallel but not coincident, then the misalignment is said to be parallel (or offset) misalignment.

If the misaligned shafts meet at a point but are not parallel, then the misalignment is called angular misalignment.

Most misalignment cases are a combination of parallel and angular misalignment. Diagnosis, as a general rule, is based upon dominant vibration at twice the rotational rate (2X) with increased rotational rate (1X) levels acting in the axial and in either the vertical or horizontal directions.

Phase relationships are very important as described below.

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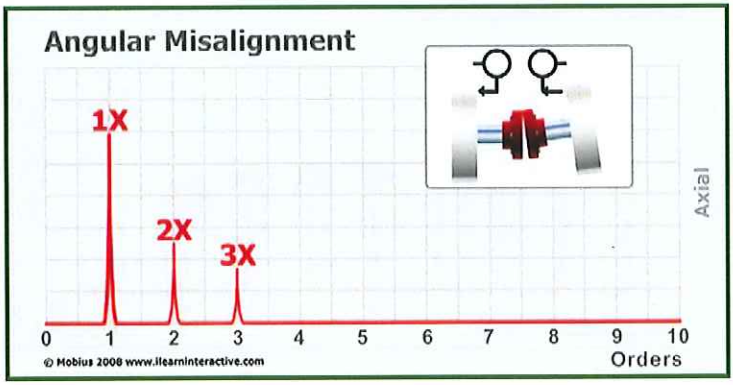
Angular Misalignment

Symptoms: High axial vibration: 1X strong but 2X and 3X can also be strong
180º across coupling in axial direction



If the misaligned shafts meet at a point but are not parallel, then the misalignment is called angular misalignment.

Angular misalignment produces a bending moment on each shaft, and this generates a strong vibration at 1X and some vibration at 2X and even 3X in the axial direction at both bearings.

There will also be fairly strong radial (vertical and horizontal) 1X and 2X levels, however these components will be in phase.

The vibration is **180º** degrees out of phase across the coupling in the axial direction, and in-phase in the radial direction.

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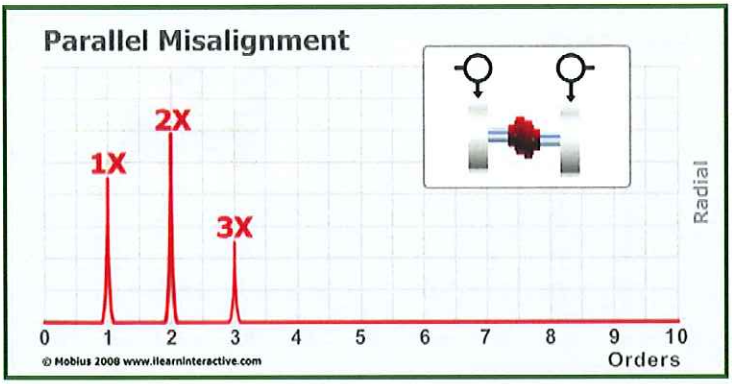
Parallel Misalignment

Symptoms: 2X radial, smaller 1X radial (V & H)
180º across coupling in radial direction



If the misaligned shaft centerlines are parallel but not coincident, then the misalignment is said to be parallel (or offset) misalignment.

Parallel misalignment produces both a shear force and bending moment on the coupled end of each shaft.

High vibration levels at 2X as well as 1X are produced in the radial (vertical and horizontal) directions on the bearings on each side of the coupling. Most often the 2X component will be higher than 1X. Depending upon the coupling type, there can be 3X, 4X all the way up to 8X peaks, particularly when misalignment is severe. In this case, the noise floor is not raised (unlike rotating looseness) and the harmonics do not continue to higher frequencies (as they do with rotating looseness).

Axial 1X and 2X levels will be low for pure parallel misalignment.

The vibration is **180º** degrees out of phase across the coupling in the radial and axial directions.

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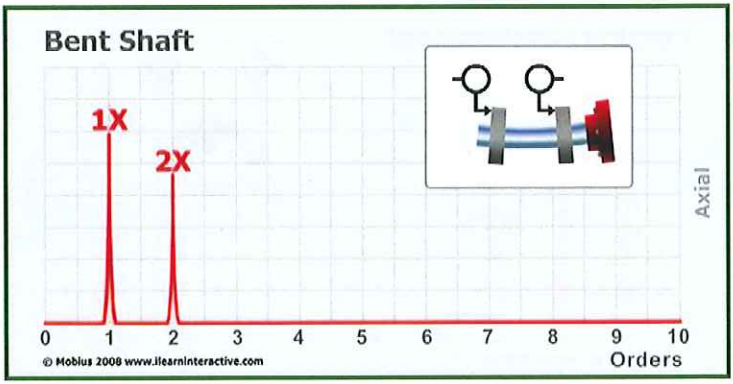
Bent Shaft

Symptoms: 1X axial
Close to 180º phase difference between bearings



A bent shaft predominantly causes high 1X axial vibration. The dominant vibration is normally at 1X if the bend is near the center of the shaft, however you will see 2X vibration if the bend is closer to the coupling.

Vertical and horizontal axis measurements will also often reveal peaks at 1X and 2X, however the key is the axial measurement.

Phase is also a good test used to diagnose a bent shaft. The phase at 1X measured in the axial directions at opposite ends of the component will be **180º** degrees out of phase.

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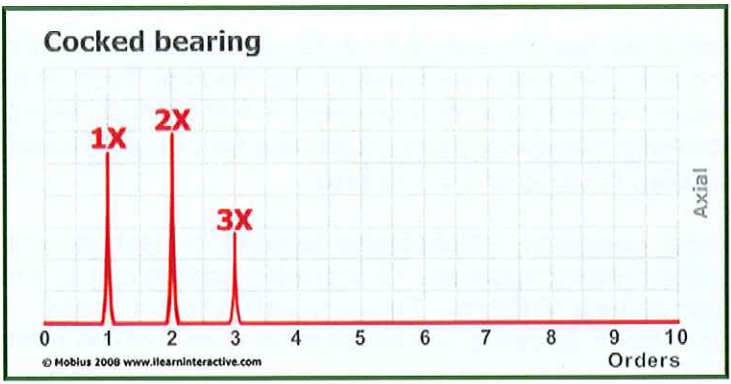
Cocked Bearing

Symptoms: 1X, 2X, and 3X axial
180º phase difference on either side of the shaft



A cocked bearing, which is a form of misalignment, will generate considerable axial vibration. Peaks will often be seen at 1X, 2X, as well as 3X.

Given that there is such a strong axial vibration, it too can be confused with misalignment, and with imbalance in an overhung pump or fan. The presence of peaks at 2X and 3X would indicate a cocked bearing condition over imbalance however.

Due to the twisting motion, there will be **180º** phase difference on either side of the shaft on the bearing (i.e. between measurements taken above and below the shaft or left and right of the shaft).

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Looseness

Symptoms: **Rotating:** 1X harmonics
Structural: 1X horizontal
Pedestal bearing: 1X, 2X, and 3X vertical

Rotating looseness is caused by excessive clearance between rotating and stationary elements of the machine such as in a bearing, while non-rotating looseness is a looseness between two normally stationary parts, such as a foot and a foundation, or a bearing housing and a machine.

Structural looseness, or looseness between a machine and its foundation, will increase the 1X vibration component in the direction of least stiffness. This is usually the horizontal direction, but it depends on the physical layout of the machine.

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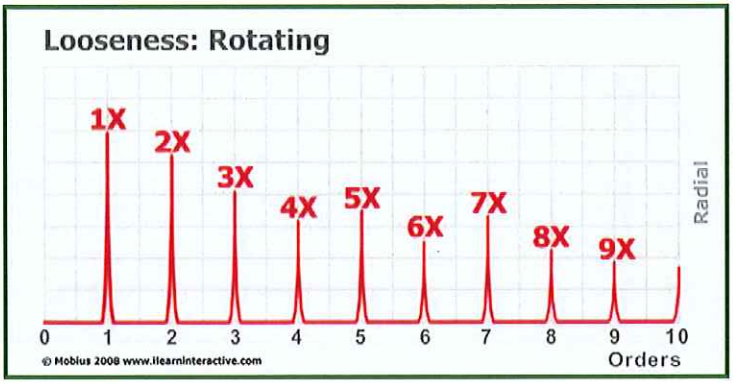
Rotating Looseness

Symptoms: 1X harmonics radial (0.5X harmonics when severe)



Excessive clearance in journal (sleeve) and rolling element bearings (bearing looseness) will produce harmonics of 1X that can extend, in some cases, above 10X.

Excessive journal bearing clearance can produce harmonics of 0.5X as shown below. They are called half order components or sub harmonics. They can be produced by rubs and severe impacting. Even 1/3 order harmonics are possible.

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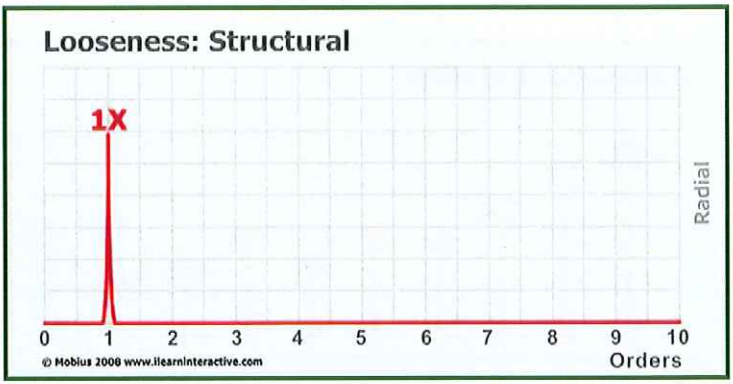
Structural Looseness

Symptoms: Structural: 1X horizontal



Looseness between a machine and its foundation will increase the 1X vibration component in the direction of least stiffness. This is usually the horizontal direction, but it depends on the physical layout of the machine.

Low-order 1X harmonics are also commonly produced if the looseness is severe. It is often hard to tell imbalance from foundation looseness or flexibility, especially in vertical machines.

If 1X horizontal is much greater than 1X vertical, looseness is suspected. If 1X horizontal is lower than or equal to 1X vertical, then imbalance is suspected. Foundation flexibility or looseness can be caused by loose bolts, corrosion, or cracking of mounting hardware. Note: If a machine has resilient mounts, then the vibration will always be greater in the horizontal axis.

Phase can be used to verify this condition. There will be a **180°** degrees phase difference between the machine and the base in the vertical direction.

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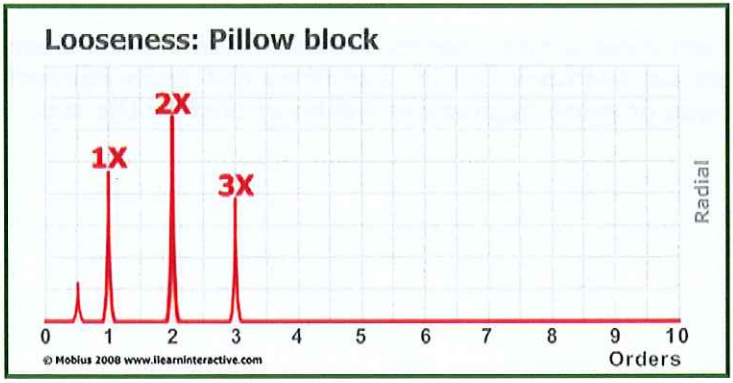
Pedestal Bearing Looseness

Symptoms: 1X, 2X, and 3X radial



The spectrum will have components at 1X, 2X and 3X (but often no more harmonics), with a 0.5X peak in more severe cases.

Phase can again be used to verify this condition. There will be a 180 degrees phase difference between the bearing and the base.

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Rotor Rub

Symptoms: 1X harmonics radial (0.5X harmonics when severe)

A rub will show similar characteristics to rotating looseness. You will see harmonics of 1X, and often half-order harmonics. Often one or more resonances will be excited by the rub.

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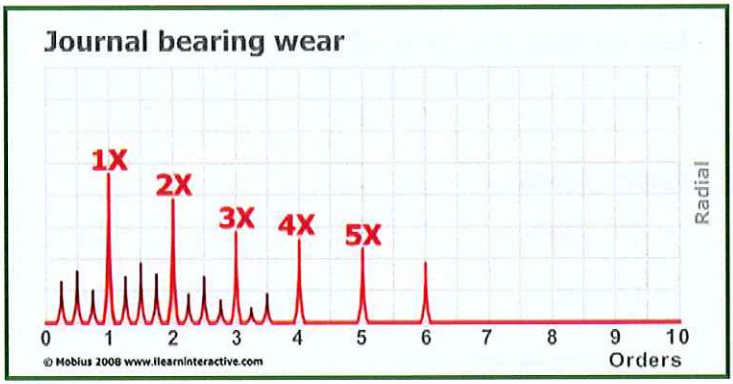
Journal Bearing Clearance

Symptoms: 1X harmonics



When there are clearance problems in sleeve (journal) bearings, the spectrum will show very similar characteristics to rotating looseness. There will be strong harmonics of shaft speed. In most cases, the vertical axis of vibration will have higher levels than horizontal.

In more severe cases, half-order and even one-third order harmonics will be present in the spectrum.

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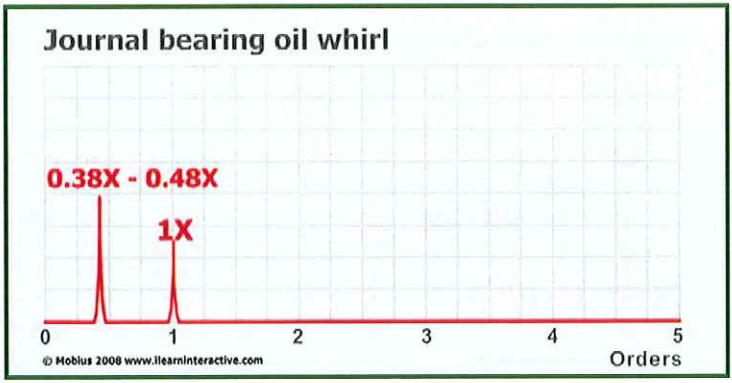
Oil Whirl

Symptoms: 0.38-0.48X in radial



Oil Whirl is a condition in which a strong vibration occurs at between 0.38X and 0.48X. It never shows up at precisely 0.5X, but is always a little lower in frequency.

It is caused by excessive clearance and light radial loading, which results in the oil film building up and forcing the journal to migrate around in the bearing at less than one-half RPM.

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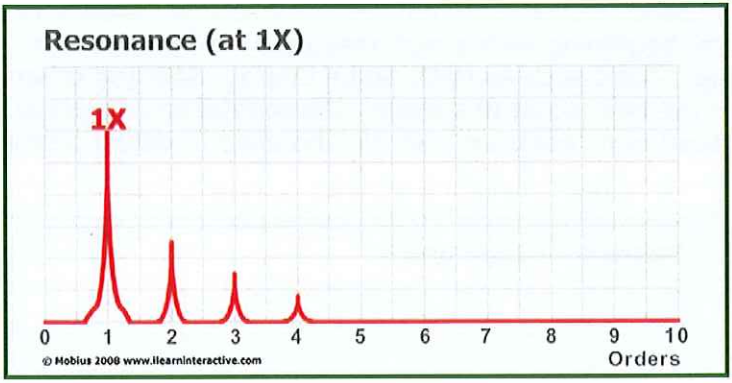
Resonance

Symptoms: "Hump" in spectrum typically in one direction only



Resonance is an operating condition where an excitation frequency is near a natural frequency of the machine structure. A natural frequency is a frequency at which a structure will vibrate if deflected and then let go.

There will typically be a high amplitude peak sitting on a "hump" in the spectrum in only one axis. Or example, the pump vane rate peak at 6X may be elevated in the horizontal direction only.

If you increase (or reduce) the frequency so that the resonance is not longer excited, the amplitude will drop significantly.

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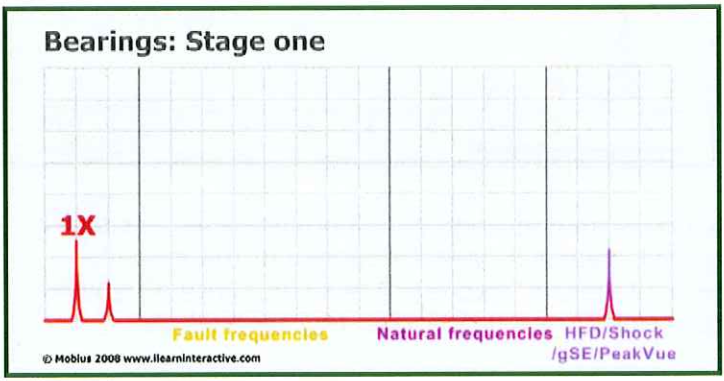
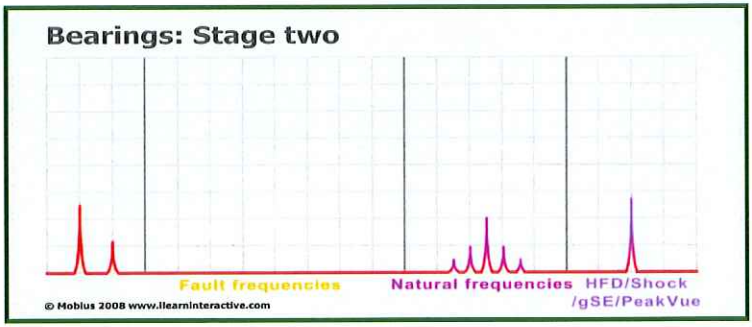
Rolling Element Bearing Wear

Symptoms: Peak (with harmonics) at non-synchronous frequencies

Faults associated with rolling element bearings follow a classic pattern, beginning with a high frequency "ringing" of the bearing. Tools such as HFD, Spike Energy, SEE and others detect the bearing at this stage. Demodulation (envelope detection) and "Peakvue" can also be used to detect bearing faults.



As the fault progresses the spectrum will change in characteristic ways. There will be peaks at non-synchronous frequencies (e.g. 3.9X, 6.45X, et.), typically with harmonics, and often with sidebands of running speed (1X) or the cage frequency.



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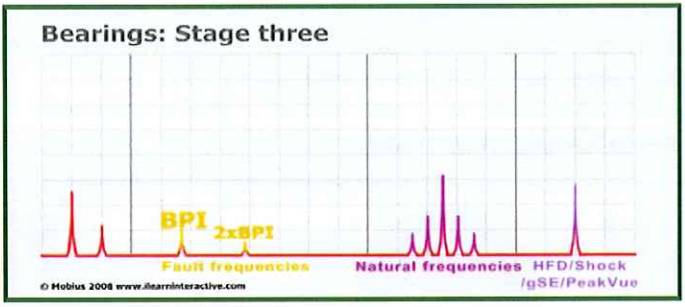

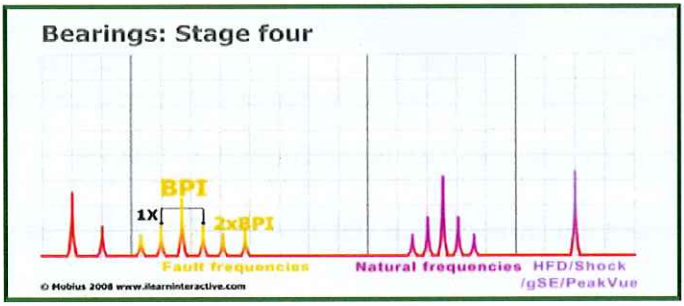

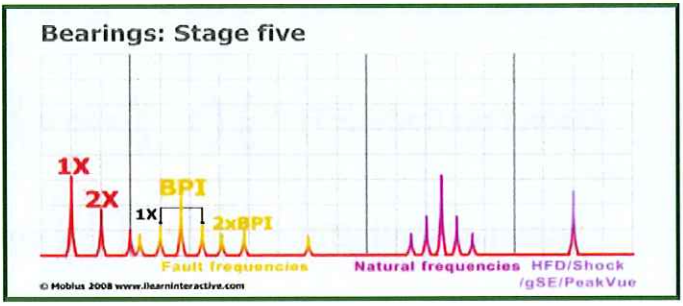

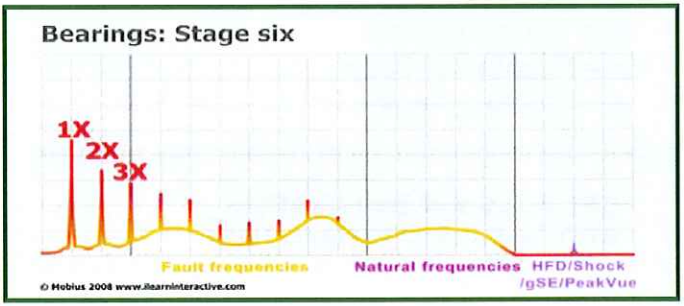

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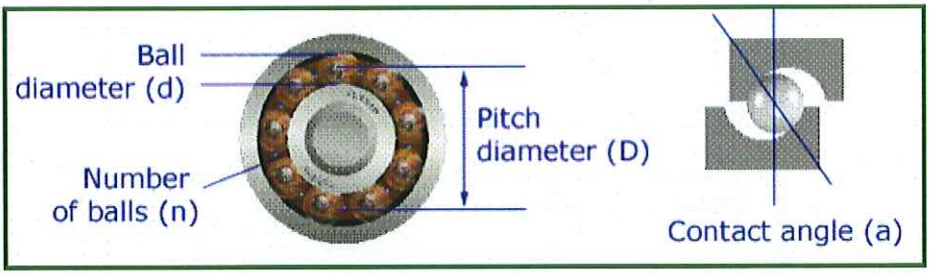
There are four forcing frequencies of interest: ball pass inner race (BPI), ball pass outer race (BPO), fundamental train (also called the cage rate) (FT), and ball spin (BS).

Given the following information:



The forcing frequencies can be calculated as follows:

$$\textbf{Defect on Inner Race (BPI)} = \frac{1}{2} n \left(1 + \frac{d}{D} \cos \alpha\right)$$

$$\textbf{Defect on Outer Race (BPO)} = \frac{1}{2} n \left(1 - \frac{d}{D} \cos \alpha\right)$$

$$\textbf{Defect on Cage (FT)} = \frac{1}{2} \left(1 - \frac{d}{D} \cos \alpha\right)$$

$$\textbf{Defect on Ball (BS)} = \frac{1}{2} \frac{D}{d} \left[1 - \left(\frac{d}{D}\right)^2 \cos^2 \alpha\right]$$

Where: **d** = Ball Diameter
D = Pitch Diameter
n = Number of Balls
A = Contact Angle

Alternatively, the following rule of thumb may be used:

BPI = 0.6 x # balls/rollers
BPO = 0.4 x # balls/rollers

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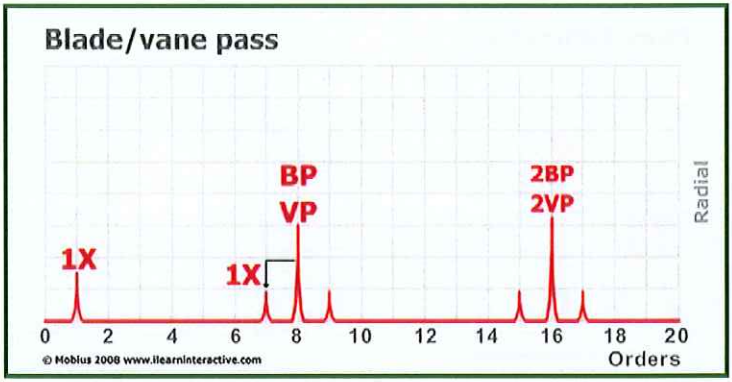
Pumps/Fans Blade/Vane Pass

Symptoms: Peak at vane pass or blade pass frequency



All pumps, fans and compressors will normally have a peak in the spectrum at the "blade pass" or "vane pass" frequency. This is the number of blades or vanes multiplied by the shaft speed.

The amplitude of the peak can increase if the gap between the blades or vanes and the stationary diffusers is not kept equal. It is also caused by obstructions and sharp bends in the flow path, in this case at the edge of the volute where it meets the discharge passage.

Vane pass = Number of vanes x RPM
Blade pass = Number of blades x RPM

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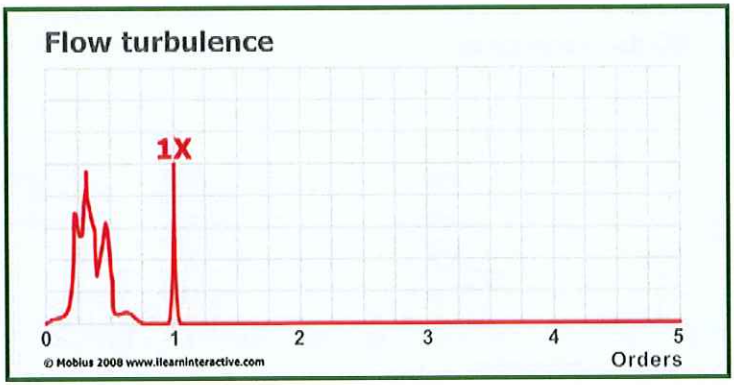
Flow Turbulence

Symptoms: Random vibration in the range 50 to 2000 CPM



Flow turbulence is due to variations in pressure or velocity of the air passing through the fan or blower.

This phenomenon generates random, low frequency vibration. It will typically be observed in the range of 50 to 2000 CPM.

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Cavitation

Symptoms: High frequency "noise"

Cavitation normally creates random, higher frequency vibration or "noise". It is often observed as a "hump" in the vibration spectrum.

Cavitation normally indicates insufficient suction pressure or starvation - i.e. low inlet pressure. If you listen to the waveform, it can often sound like gravel in the pump.

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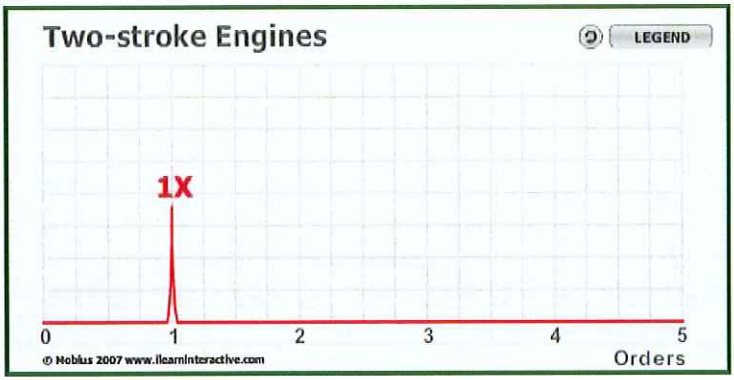
Reciprocating Machines

Symptoms: 0.5X peak for a four-stroke engine
1X peak for a two-stroke engine



The vibration level on reciprocating machinery is commonly very high.

If you have a four-stroke engine, then the engine fires every other rotation, which will result in a strong peak at 0.5X.

In the case of a two-stroke engine, such as many diesels, the engine will fire for every stroke; therefore you will see a strong 1X peak.

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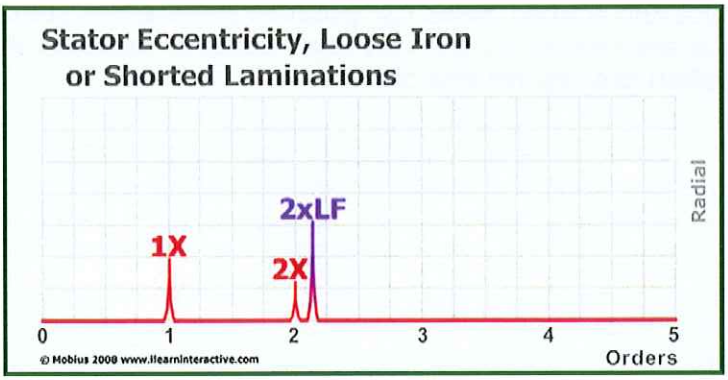
Stator Eccentricity

Symptoms: Twice line frequency (100 or 120 Hz) radial



Stator problems will generate high vibration at twice the line frequency (100 or 120 Hz). Stator eccentricity produces an uneven stationary air gap between the rotor and stator that produces a very directional source of vibration.

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Soft Foot

Symptoms: Twice line frequency (100 or 120 Hz) radial

Soft foot and warped bases can produce an eccentric stator. Altering the tension on the hold down bolts, or repairing the foundation can resolve this problem.

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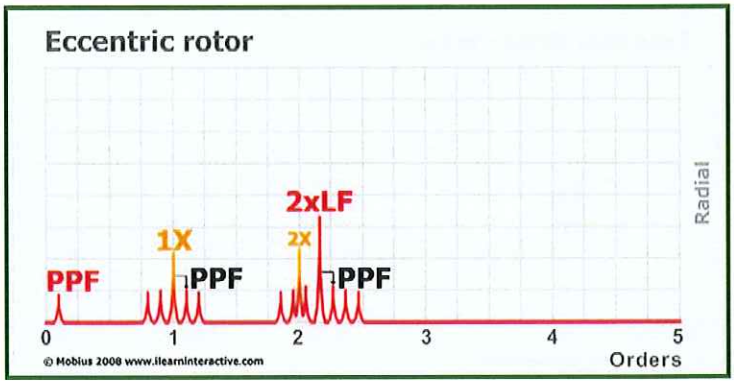
Eccentric Rotor

Symptoms: Pole pass sidebands around 1X and 100/120 Hz



Eccentric rotors produce a rotating variable air gap between the rotor and the stator, which induces a pulsating source of vibration. You will see the twice line frequency component, however this time there will be pole pass sidebands around this frequency and the 1X peak.

The pole pass frequency is the slip frequency times the number of poles. The slip frequency is the difference between the actual RPM and the synchronous speed.

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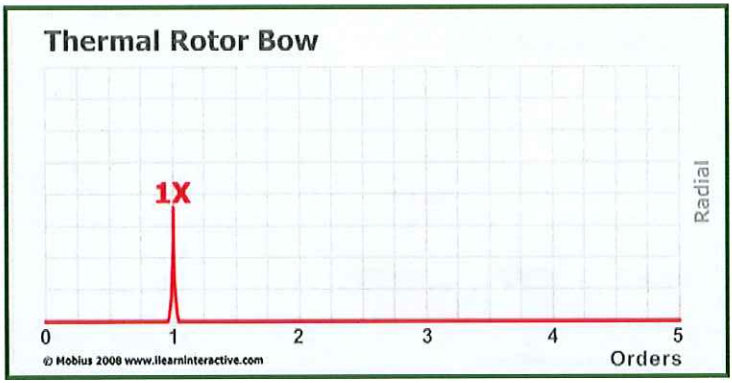
Rotor Bow

Symptoms: 1X radial



Uneven heating of the rotor due to unbalanced rotor bar current distribution causes the rotor to warp, or "bow", and rotor bow results in an imbalance condition with all its usual symptoms. It can be detected by the fact that it goes away when the motor is cold. Local heating can be so severe in motors that the offending bar can actually melt and lodge in the air gap.

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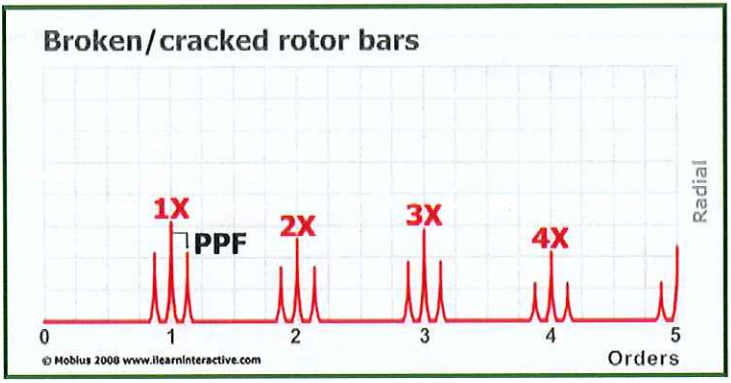
Cracked or Broken Rotor Bars

Symptoms: Pole pass sidebands around 1X and harmonics



Cracked rotor bars will generate pole pass frequency sidebands around 1X and its harmonics (2X, 3X, and so on). You will often see a very busy spectrum with harmonics of 1X, each with "skirts" of pole pass sidebands.

The pole pass frequency is the slip frequency times the number of poles. The slip frequency is the difference between the actual RPM and the synchronous speed.

An induction motor with defective rotor bars will produce a vibration signature that slowly varies up and down in amplitude at twice the slip frequency of the motor. This phenomenon is called beating, and can often be heard as well as measured. The amplitude and frequency of the beats are dependent on the load on the motor (because that affects the slip frequency).

Motor current analysis is very helpful when assessing the damage to rotor bars.

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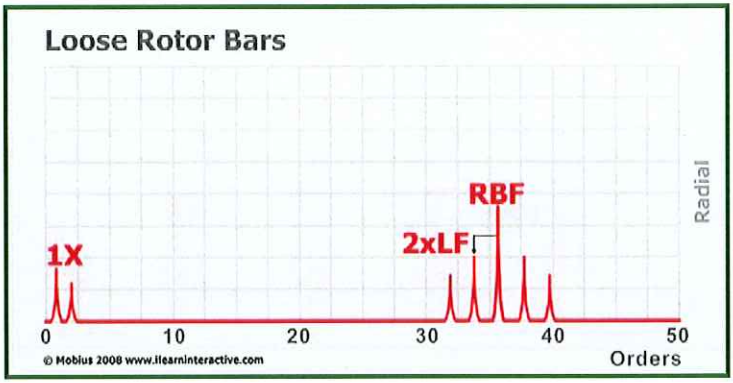
Loose Rotor Bars

Symptoms: 100/120 Hz sidebands around rotor bar pass frequency



If there are loose rotor bars there will be a peak at the rotor bar pass frequency (RBF - the number of rotor bars times the RPM), with sidebands of twice line frequency (100 or 120 Hz). Even if you do not know the number of rotor bars, if you see a high frequency with twice line frequency sidebands, you can be somewhat confident that this fault condition exists.

Rotor bar pass frequency
= Number of rotor bars X Running speed

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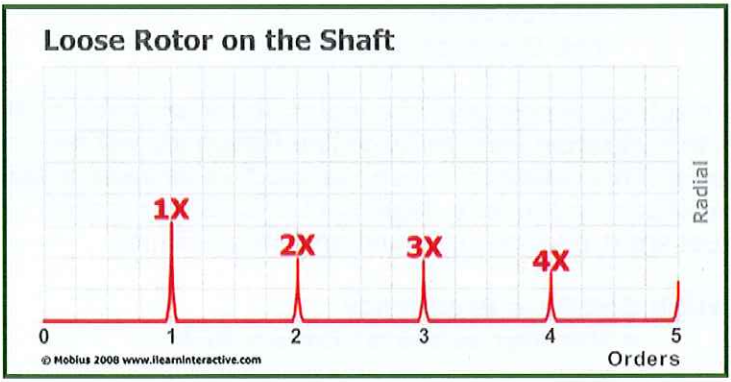
Loose Rotor

Symptoms: High 1X and harmonics



Sometimes the rotor can slip on the shaft, usually intermittently depending on temperature, and this causes severe vibration at 1X and harmonics. Abrupt changes in load or line voltage can instigate this condition.

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Loose Stator Windings

Symptoms: High 100/120 Hz radial
High Coil Pass Frequency
1X sidebands
(AC Synchronous Motors)

If the electrical windings of the motor stator are even a little loose, the vibration level at twice line frequency will be increased. This condition is very destructive because it abrades the insulation on the wire, leading to shorted turns and eventual short circuits to ground and stator failure.

High Coil Pass Frequency
= Number of Stator Coils x RPM

Number of Stator Coils
= Number of Poles x Number of Coils per Pole

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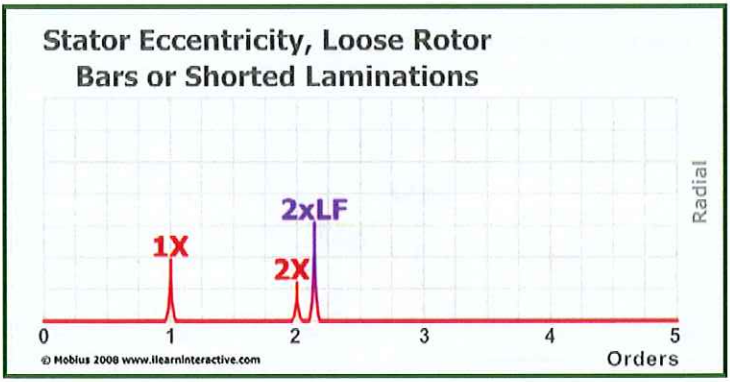
Lamination Problems

Symptoms: High 100/120 Hz radial



The rotor and stator of AC motors are made of thin laminations that are isolated from each other. If the laminations are shorted together, local heating and resultant thermal warping will occur.

Shorted laminations also cause higher twice line frequency vibration levels. The warping can cause the 1X level to increase, and often pole pass sidebands are observed.

The pole pass frequency is the slip frequency times the number of poles. The slip frequency is the difference between the actual RPM and the synchronous speed.

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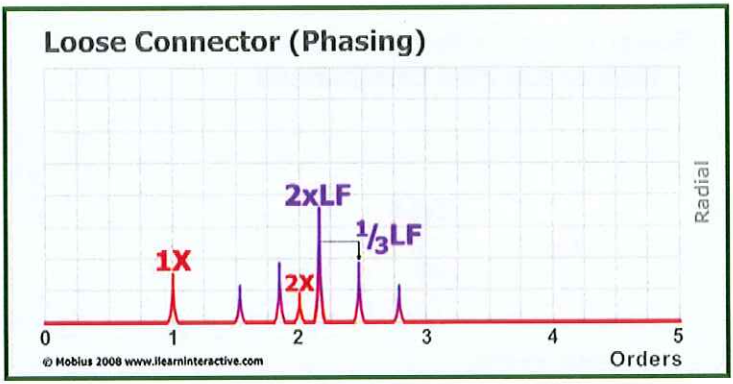
Loose Connections

Symptoms: High 100/120 Hz with 16.67/20 Hz sidebands



Phasing problems due to loose connectors can cause excessive vibration at twice line frequency (100 or 120 Hz), with sidebands of one-third line frequency (16.67 or 20 Hz).

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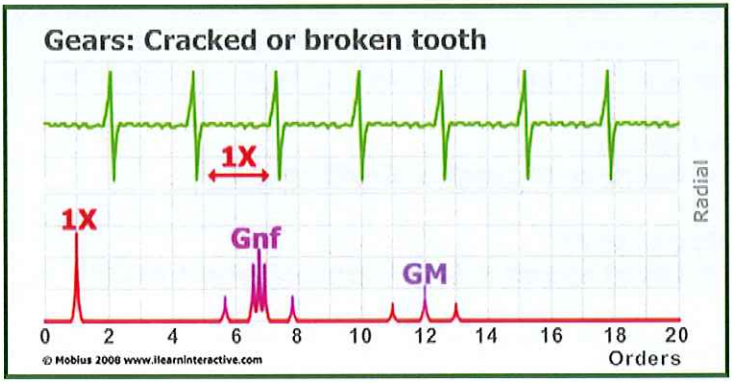
Gear Faults

You will normally find peaks at the shaft speeds and the gear mesh frequency, however they will be low level. There may be a 2X and 3X GM peak, and there may be sidebands of shaft speed around the gear mesh frequency. There may also be a peak at the natural frequency of the gears.

These frequencies will be most prominent in the radial direction for spur gears, and in the axial direction for helical gears.

Gear mesh = Number of teeth x Shaft speed
Output speed = Input speed x Input teeth/Output teeth

Time waveform analysis is a powerful tool when it comes to analyzing measurements from gearboxes. As each tooth meshes you will see a pulse in the waveform. You can typically study the time waveform and count the teeth. Depending upon the nature of the fault, you may see one of the impacts/pulses per cycle at a higher amplitude, or lower amplitude (if it were missing).



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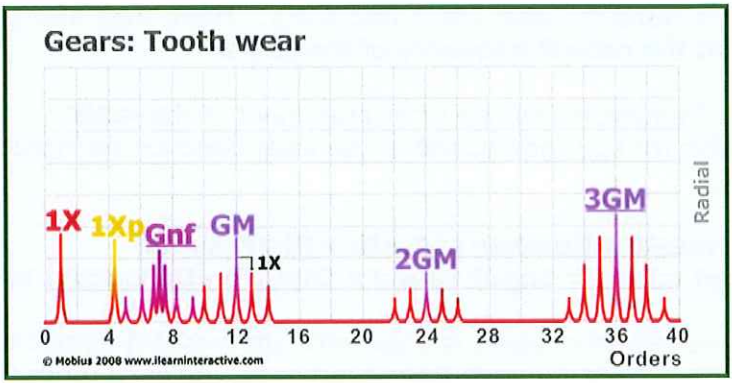
Gear Tooth Wear

Symptoms: 1X sidebands around the gearmesh frequency
Harmonics of gearmesh frequency



When teeth begin to wear, two things will happen. The first is that the sidebands of gear mesh will increase in level. The sidebands will correspond to the speed of the gear with the wear.

The second thing that occurs is that the natural frequency of the gear is excited. This peak will also exhibit sidebands, and as a natural frequency, it is likely to have a broader base.

Gear mesh
= Number of teeth x Shaft speed

Output speed
= Input speed x Input teeth/Output teeth

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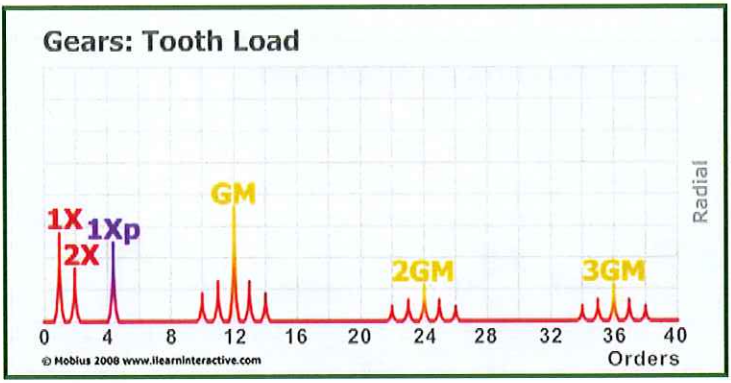
Gear Tooth Load

Symptoms: High gearmesh frequency



The level of the tooth mesh frequency is dependent on the alignment of the shafts carrying the gears, and the load on the gear. A high peak at the gear mesh frequency does not necessarily indicate a problem.

Gear mesh
= Number of teeth x Shaft speed

Output speed
= Input speed x Input teeth/Output teeth

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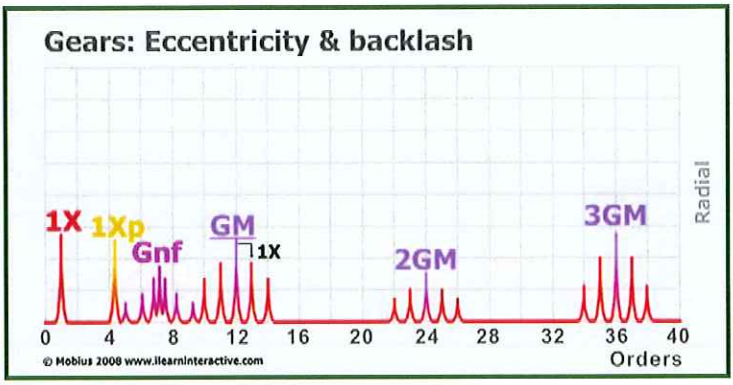
Gear Backlash

Symptoms: 1X sidebands around the gearmesh frequency
High gear natural frequency



Gear backlash will generate shaft speed sidebands around the gearmesh frequency. The gear mesh peak and the gear natural frequency peak will often decrease with increased load when this problem exists.

Gear mesh
= Number of teeth x Shaft speed

Output speed
= Input speed x Input teeth/Output teeth

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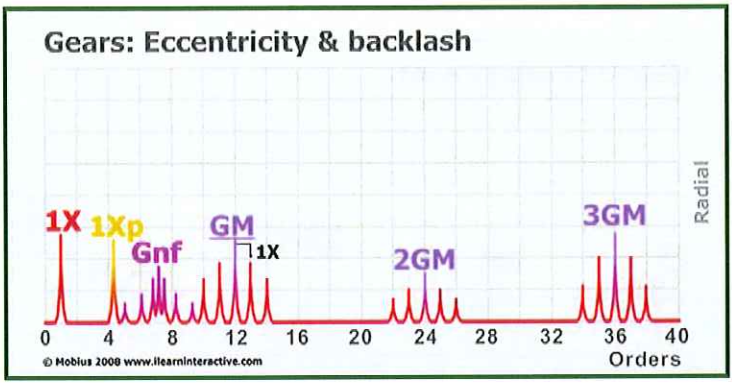
Eccentric Gears

Symptoms: 1X sideband around the gearmesh frequency



For eccentric gears and gears with bent shafts, you will see shaft speed (of the offending gear) sidebands of the gearmesh frequency, however often you will only see a single sideband, rather than an entire family.

Gear mesh
= Number of teeth x Shaft speed

Output speed
= Input speed x Input teeth/Output teeth

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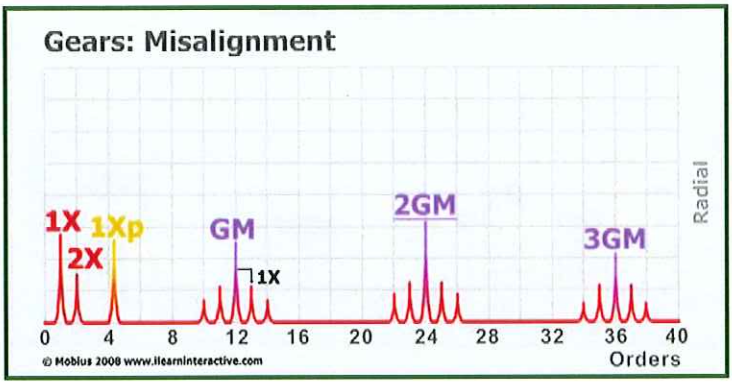
Misaligned Gears

Symptoms: 1X sideband around the gearmesh frequency
Harmonics of gearmesh



Misaligned gears will generate high gearmesh frequencies with sidebands, however it is common to have harmonics of gearmesh frequency, with higher levels at twice and three times gear mesh frequency. It is therefore important to set your frequency range (Fmax) high enough to see these frequencies.

Gear mesh
= Number of teeth x Shaft speed

Output speed
= Input speed x Input teeth/Output teeth

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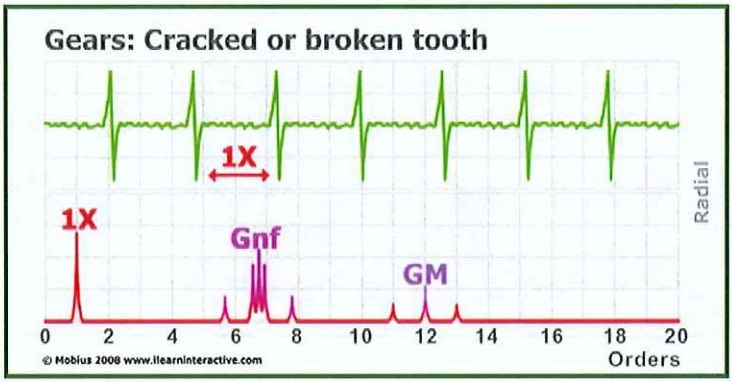
Cracked or Broken Gear Tooth

Symptoms: High 1X radial
Gear natural frequency
1X sidebands around the gearmesh frequency



A cracked or broken tooth will generate a high amplitude peak at the turning speed of that gear, and it will cause the gear natural frequency to be excited. There will be sidebands of the turning speed of that gear.

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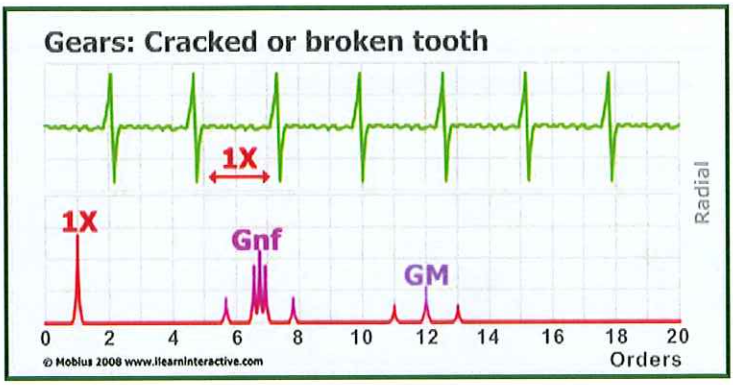
However, the best way to see a cracked or broken tooth is via the time waveform. If there were twelve teeth, one of 12 pulses in the waveform will be very different to the other pulses. Naturally, the time difference between these pulses will be equal to the period of the turning speed of that gear (the tooth comes into mesh once per revolution).



Gear mesh
= Number of teeth x Shaft speed

Output speed
= Input speed x Input teeth/Output teeth

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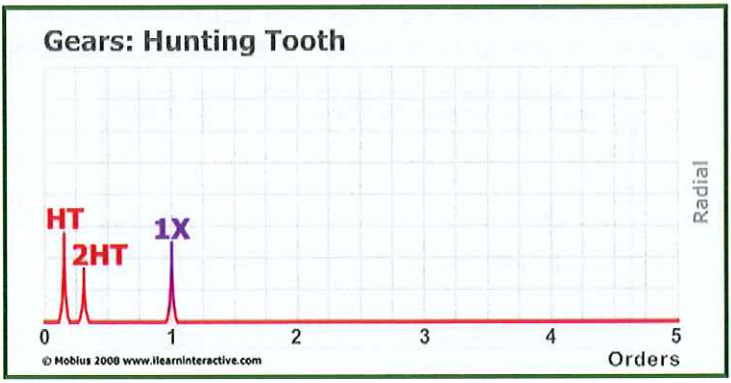
Hunting Tooth Frequency

Symptoms: Hunting tooth frequency and 2xHT



The so-called "hunting tooth frequency" is the rate at which a tooth in one gear mates with a particular tooth in the other gear. If the gear ratio is an integer such a 1, 2 or 3, the hunting tooth frequency will be the RPM of the larger gear, and the same teeth will be in contact once per revolution. This will cause uneven wear on the gears - a small defect in one tooth will repeatedly contact the same teeth in the other gear causing localized wear on those teeth.

In practice, the hunting tooth frequency is used to detect faults on both the gear and pinion that may have occurred during manufacturing or as a result of mishandling. It is typically a low frequency, and you can hear a "growling" sound from the gearbox.

The hunting tooth frequency of a pair of gears is the gear mesh frequency divided by the least common multiple of the numbers of teeth on the two gears. The least common multiple is often just the product of the numbers of teeth.

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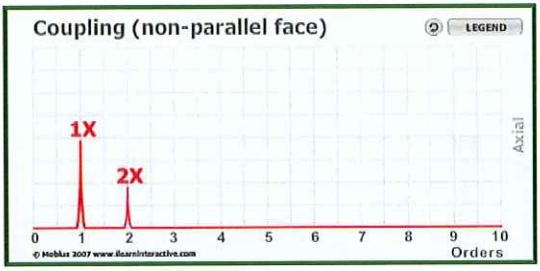
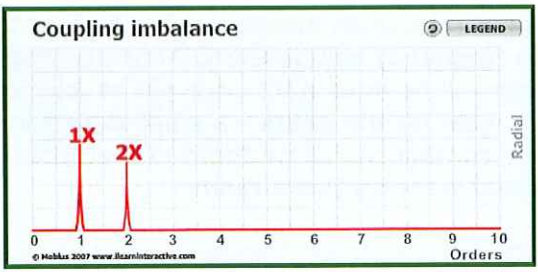
Coupling Faults

Symptoms: 1X and 2X

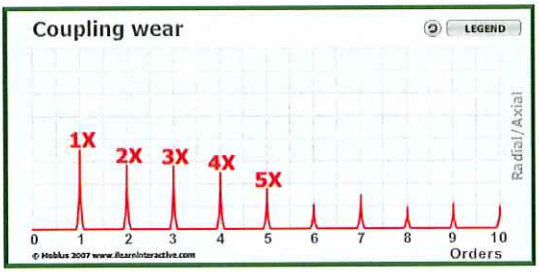
If the coupling is not true, i.e., has non-parallel flange faces, a vibration pattern similar to angular misalignment is produced.



Coupling imbalance is also a common problem, and results in high 1X and 2X radial components.



Coupling wear can produce all the symptoms of misalignment and looseness.



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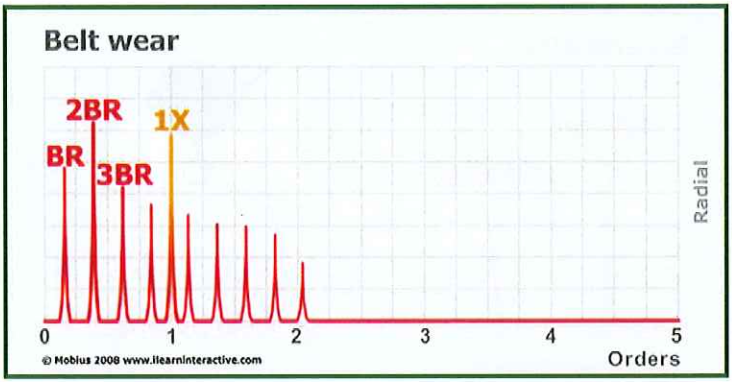
Worn or Loose Belts

Symptoms: Belt rate with sidebands



If a belt is worn or loose you will witness a peak at the belt rate, and harmonics, with twice this frequency (2BR) the highest - when there are two sheaves.

The key forcing frequency is known as the "belt rate" or "fundamental belt pass frequency". It is the rate at which a point on the belt passes a fixed reference point. It is always less that the speed of either sheave.

It is calculated as follows:

$$\textbf{Driven RPM} = \frac{\textbf{Driving RPM x Driving sheave diameter}}{\textbf{Driven sheave diameter}}$$

Belt freq
= PI x Sheave RPM x Sheave diameter/Belt length

Where PI = 3.1416

For timing belts we have a second forcing frequency to consider, known as the "timing belt frequency".

Timing belt freq = Belt Freq x # Teeth on belt
or
Timing belt freq = Sheave RPM x # Teeth on sheave

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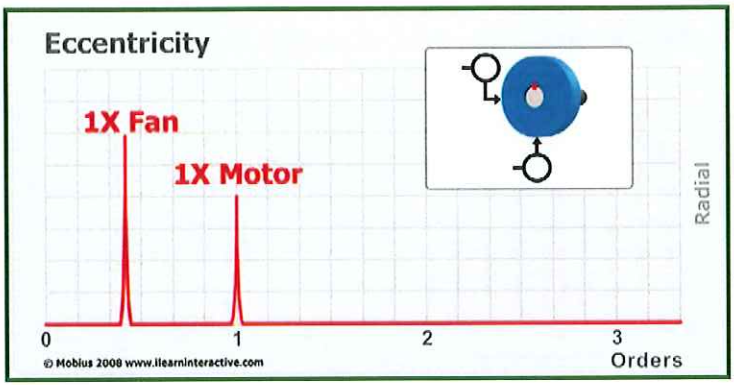
Eccentric Sheaves/Pulleys

Symptoms: High 1X radial



Eccentric sheaves will generate a strong 1X radial peak, especially in the direction parallel to the belts. This condition is very common, and mimics imbalance. This condition can be checked by removing the belts and repeating the measurement. 1X vibration of an eccentric sheave will also show up at the other sheave.

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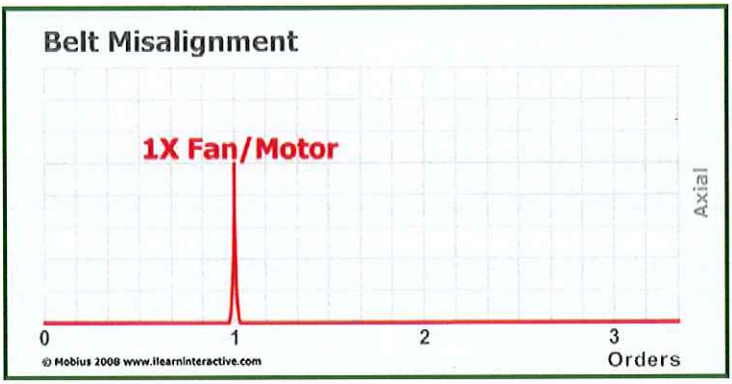
Misaligned Sheaves/Pulleys

Symptoms: High 1X axial

Misalignment of sheaves produces high vibration at 1X, predominantly in the axial direction. On occasion you will also see harmonics of belt rate (belt frequency) in the axial direction.



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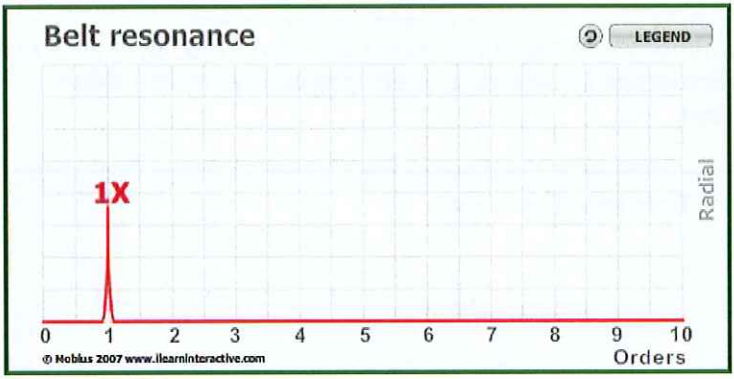
Belt Resonance

Symptoms: High 1X radial



Resonance in the belt can cause high amplitudes if the belt's natural frequency should happen to coincide with either the driving or driven sheave RPM. The natural frequency can be altered by either changing the length or tension of the belt.

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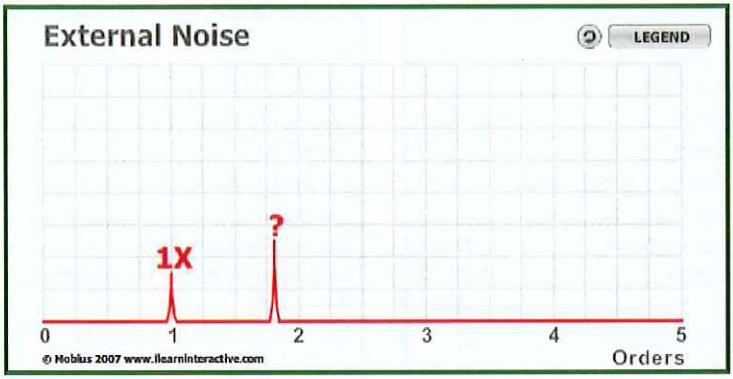
External Noise

Symptoms: Non-synchronous peak



You will often find a peak in a spectrum that is difficult to explain. Before you jump to conclusions, you may like to rule-out the possibility that the vibration is from another machine or process.

The peak will typically be at a non-synchronous frequency (it would be too much of a coincidence for it to be EXACTLY that same as your machine speed). There are two ways to verify that the vibration is from another machine:

- Stop the machine (or vary the speed) and see if the vibration is still present.
- Check local machines for the same frequency source.

If you find that it is from an external machine, you may not want to ignore it. If the machine in question is often stopped for long periods of time, damage can occur to bearings through a process called *brinnelling*.

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Page References by Symptom

1X

Raised Noise Floor D-4
Dynamic Imbalance D-6
Static Imbalance D-7
Couple Imbalance D-8
Imbalance: Overhung Machines..... D-9
Imbalance: Vertical Machines..... D-10
Eccentric Rotor or Gear D-11
Eccentric Sheaves..... D-12
Misalignment..... D-13
Angular Misalignment..... D-14
Parallel Misalignment D-15
Bent Shaft D-16
Cocked Bearing D-17
Looseness..... D-18
Rotating Looseness D-19
Structural Looseness..... D-20
Pedestal Bearing Looseness D-21
Rotor Rub D-22
Journal Bearing Clearance..... D-23
Resonance D-25
Rolling Element Bearing Wear D-26
Reciprocating Machines D-32
Eccentric Rotor D-35
Rotor Bow..... D-36
Cracked or Broken Rotor Bars D-37
Loose Rotor D-39
Cracked or Broken Tooth D-49
Coupling Faults..... D-52
Eccentric Sheaves/Pulleys..... D-54
Misaligned Sheaves/Pulleys..... D-55
Belt Resonance..... D-56

2X

Misalignment..... D-13
Angular Misalignment D-14
Parallel Misalignment..... D-15
Bent Shaft D-16
Cocked Bearing..... D-17
Looseness D-18
Rotating Looseness D-19
Pedestal Bearing Looseness..... D-21
Rotor Rub D-22
Journal Bearing Clearance..... D-23
Coupling Faults..... D-52

3X - 8X

Misalignment..... D-13
Angular Misalignment D-14
Parallel Misalignment..... D-15
Cocked Bearing..... D-17
Looseness D-18
Rotating Looseness D-19
Pedestal Bearing Looseness..... D-21
Rotor Rub D-22
Journal Bearing Clearance..... D-23
Pumps/Fans Blade/Vane Pass D-29
Coupling Faults..... D-52

Page References by Symptom

H

Rotating Looseness D-19
Rotor Rub D-22
Rolling Element Bearing Wear D-26
Cracked or Broken Rotor Bars D-37
Loose Rotor D-39
Gear Faults D-43
Gear Tooth Wear D-44
Gear Tooth Load D-45
Gear Backlash D-46
Eccentric Gears D-47
Misaligned Gears D-48
Cracked or Broken Tooth D-49
Hunting Tooth Frequency D-51
Coupling Faults D-52
Worn or Loose Belts D-53

S

Rolling Element Bearing Wear D-26
Eccentric Rotor D-35
Cracked or Broken Rotor Bars D-37
Loose Rotor Bars D-38
Loose Stator Windings D-40
Loose Connections D-42
Gear Faults D-43
Gear Tooth Wear D-44
Gear Tooth Load D-45
Gear Backlash D-46
Eccentric Gears D-47
Misaligned Gears D-48
Cracked or Broken Tooth D-49

NS

Rolling Element Bearing Wear D-26
Hunting Tooth Frequency D-51
External Noise D-57

NF

Ski-Slope D-3
Raised Noise Floor D-4
Flow Turbulence D-30
Cavitation D-31

SS

Oil Whirl D-24
Flow Turbulence D-30
Reciprocating Machines D-32
Worn or Loose Belts D-53

LF

Stator Eccentricity D-33
Soft Foot D-34
Eccentric Rotor D-35
Loose Rotor Bars D-38
Loose Rotor D-39
Lamination Problems D-41
Loose Connections D-42

Useful Charts, Diagrams & Tables

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$$T = T_s \times N = \frac{N}{F_s} = \frac{N}{256 \times F_{max}} = \frac{\text{lines}}{F_{max}}$$

T = Time required to collect the waveform

T_s = Time between each sample

F_s = Sampling rate = Samples per second

N = Number of samples (1024, 2048, 4096, etc.)

Require spectural line

$\geq 2 \times$ window Fac $\times F_{max}$

separate fre

$$\text{Resolution} = \frac{F_{max}}{\text{lines}}$$

Bandwidth = Resolution x window factor

window factor = 1 (no window) or 1.5 (Hamming window)

Separate ≥ 2 resolution x window Factor

accuracy of f at peak = $\pm \frac{1}{2} \times$ resolution

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Unit Conversions

$$D = \frac{27{,}009\ V}{F} \qquad D = \frac{2.53X10^{9}\ A}{F^{2}}$$

$$V = \frac{93{,}712\ A}{F} \qquad V = \frac{D\ F}{27{,}009}$$

$$A = \frac{D\ F^{2}}{2.53X10^{9}} \qquad A = \frac{V\ F}{93{,}712}$$

D = Displacement: micron pk-pk
V = Velocity: mm/sec rms
A = Acceleration: g rms
F = Frequency: CPM

$$D = \frac{19{,}098\ V}{F} \qquad D = \frac{9.958x10^{7}A}{F^{2}}$$

$$V = \frac{5{,}217\ A}{F} \qquad V = \frac{D\ F}{19{,}098}$$

$$A = \frac{D\ F^{2}}{9.958x10^{7}} \qquad A = \frac{V\ F}{5{,}217}$$

D = Displacement: mils pk-pk
V = Velocity: in/sec pk
A = Acceleration: g rms
F = Frequency: CPM

pk-pk = 2 x pk
rms = 0.707 x pk

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1X Vibration Levels

Operating Speeds 1500 - 3600 RPM

Reduce by 4dB (x0.63) for slower machines
Increase by 4dB (x1.6) for large, high speed machines
Increase by 8dB (x2.5) for reciprocating machines

1 X Vibration Level			Diagnosis	Repair Priority
in/sec pk	mm/s rms	VdB (US)		
<0.134	<2.5	<108	Slight Imbalance	No Recommendation
0.134 - 0.28	2.5 - 5.0	108 - 114	Moderate Imbalance	Desirable
0.28 - 0.88	5.0 - 15.8	114 - 124	Serious Imbalance	Important
>0.88	>15.8	>124	Extreme Imbalance	Mandatory

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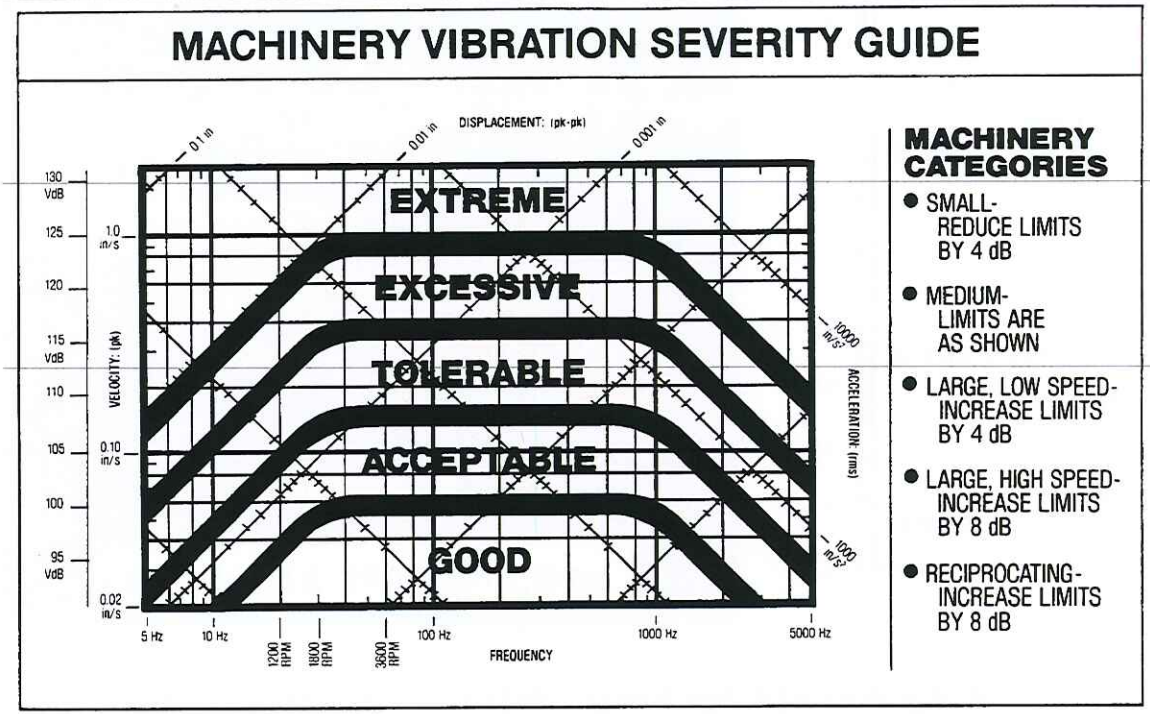
Vibration Severity Chart



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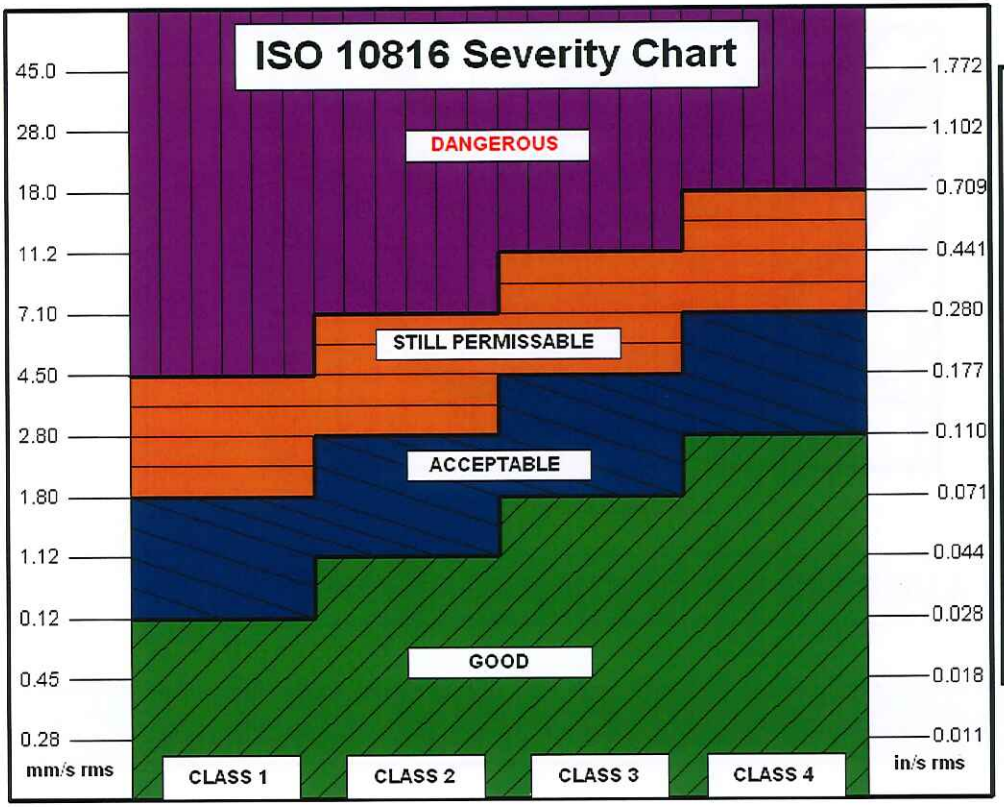
ISO 10816-1 Vibration Severity Chart



CLASS 1 Small machines, especially production electrical motors up to 15kW

CLASS 2 Medium sized machines, especially electrical motors >15kW to 75kW without special foundations

CLASS 3 Large machines on heavy foundations

CLASS 4 Largest machines and turbo machines with special foundations

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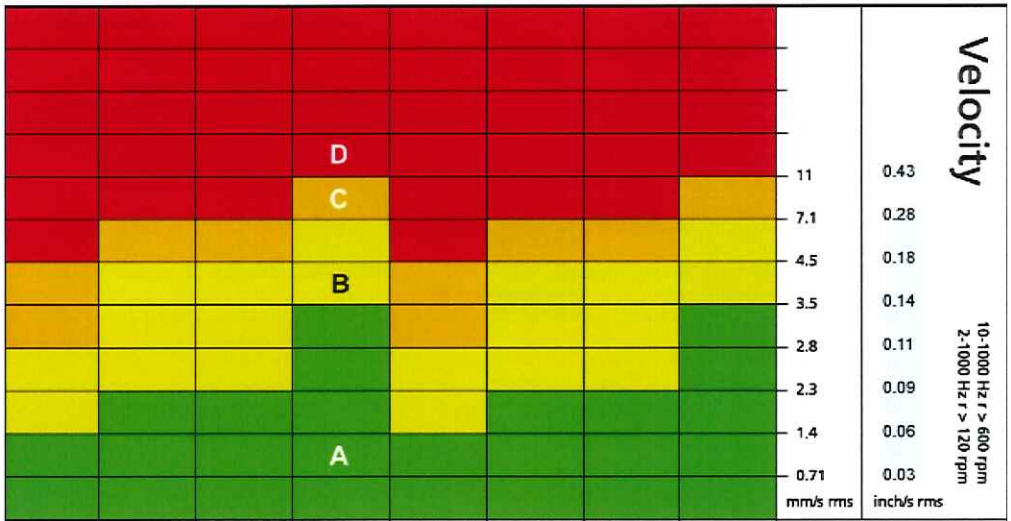
ISO 10816-3 Vibration Severity Chart



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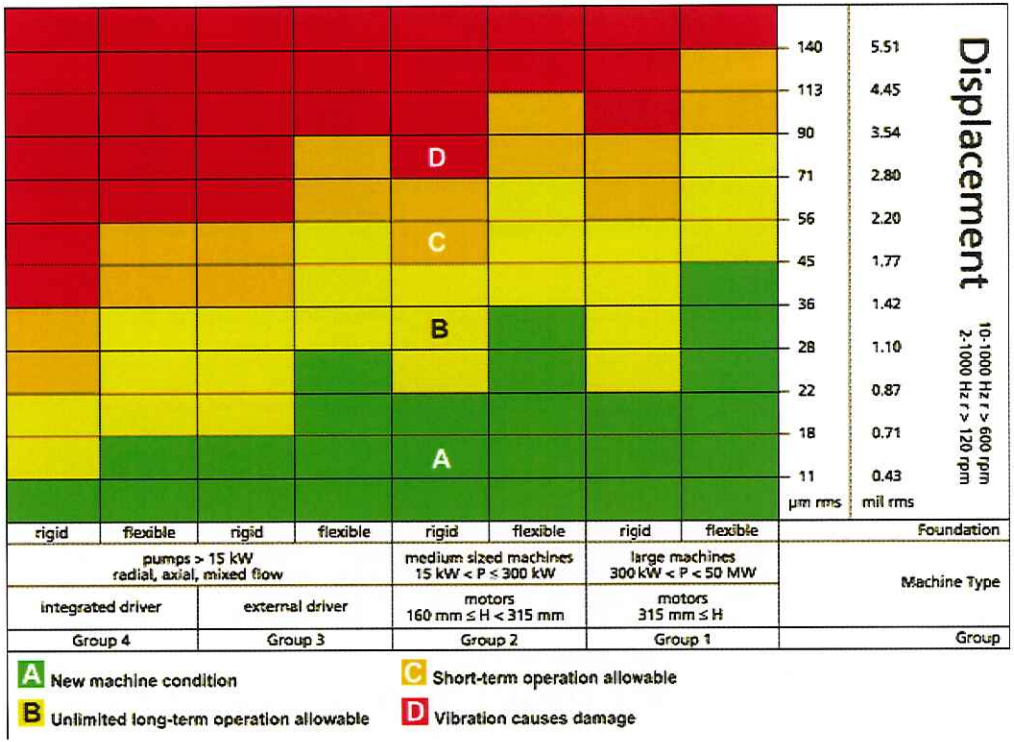
ISO 10816-3 Vibration Severity Chart



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Belt Forcing Frequency

$$\text{Belt Frequency} = \frac{\pi \times \text{Sheave RPM} \times \text{Sheave Diameter}}{\text{Belt Length}}$$

Where $\pi = 3.1416$

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Bearing Forcing Frequencies

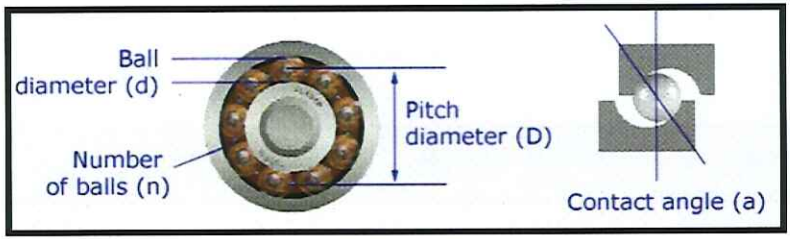
$$\text{Defect on Inner Race (BPI)} = \frac{1}{2} n \left(1 + \frac{d}{D} \cos \alpha\right)$$

$$\text{Defect on Outer Race (BPO)} = \frac{1}{2} n \left(1 - \frac{d}{D} \cos \alpha\right)$$

$$\text{Defect on Cage (FT)} = \frac{1}{2} \left(1 - \frac{d}{D} \cos \alpha\right)$$

$$\text{Defect on Ball (BS)} = \frac{1}{2} \frac{D}{d} \left[1 - \left(\frac{d}{D}\right)^2 \cos^2 \alpha\right]$$

Where:
d = Ball Diameter
D = Pitch Diameter
n = Number of Balls
A = Contact Angle



Quick Calculation

BPI = 0.6 x Number of Balls

BPO = 0.4 x Number of Balls

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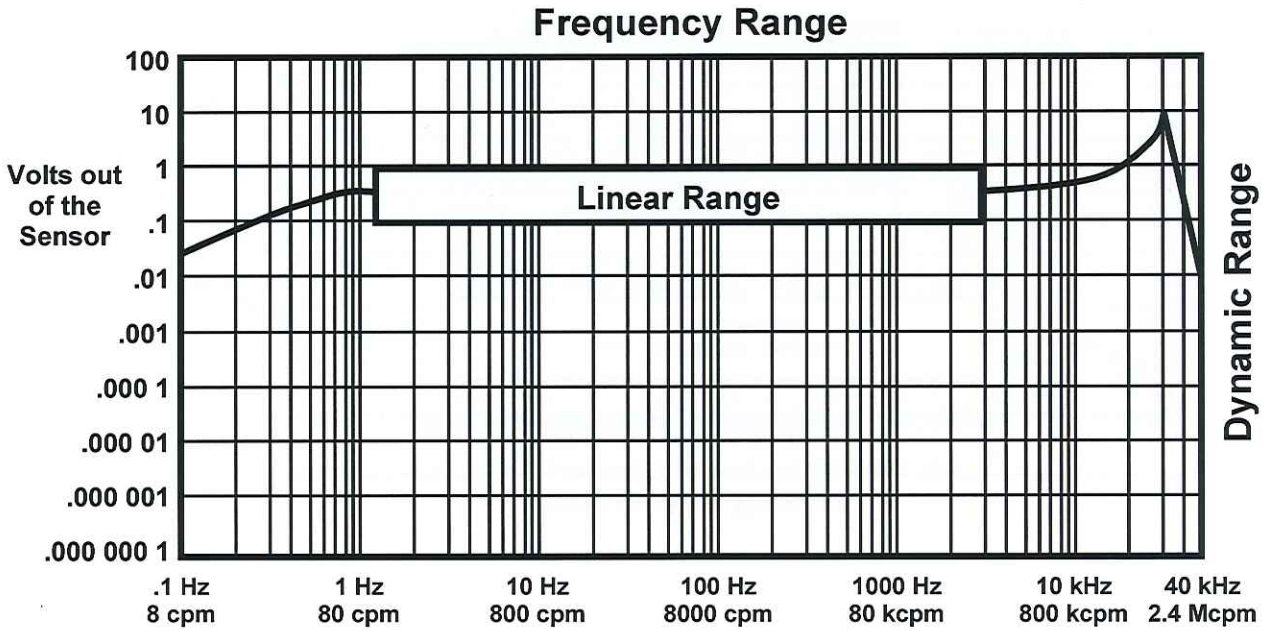
Transducer Linear Range



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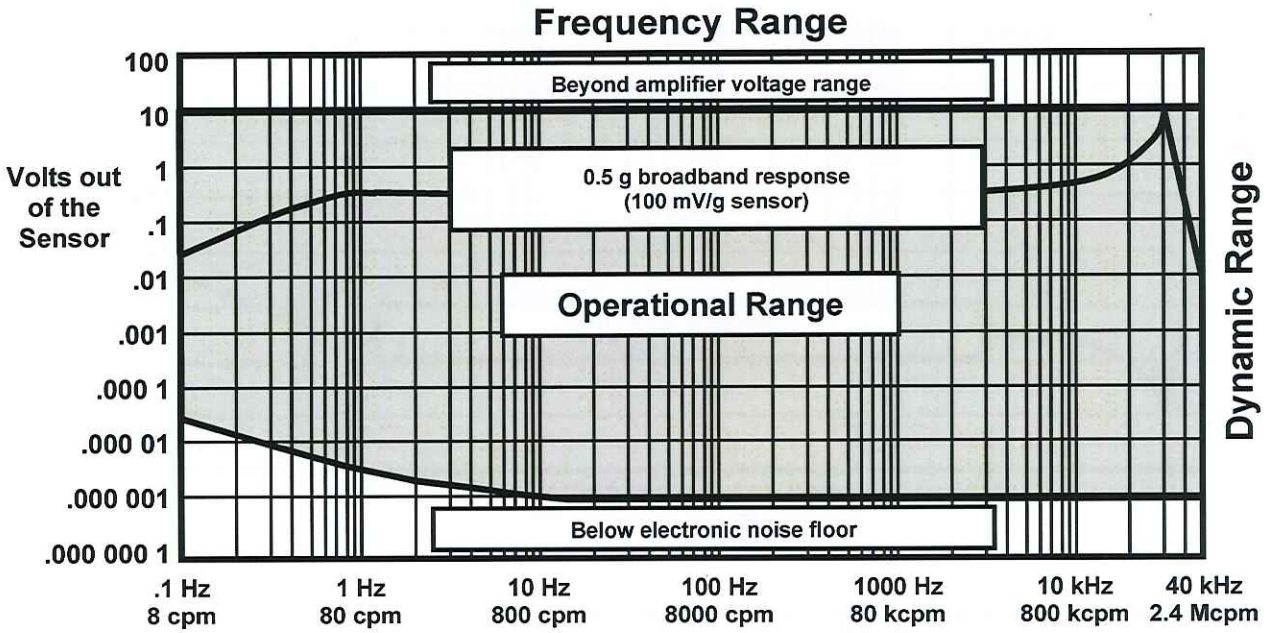
Transducer Operating Regions



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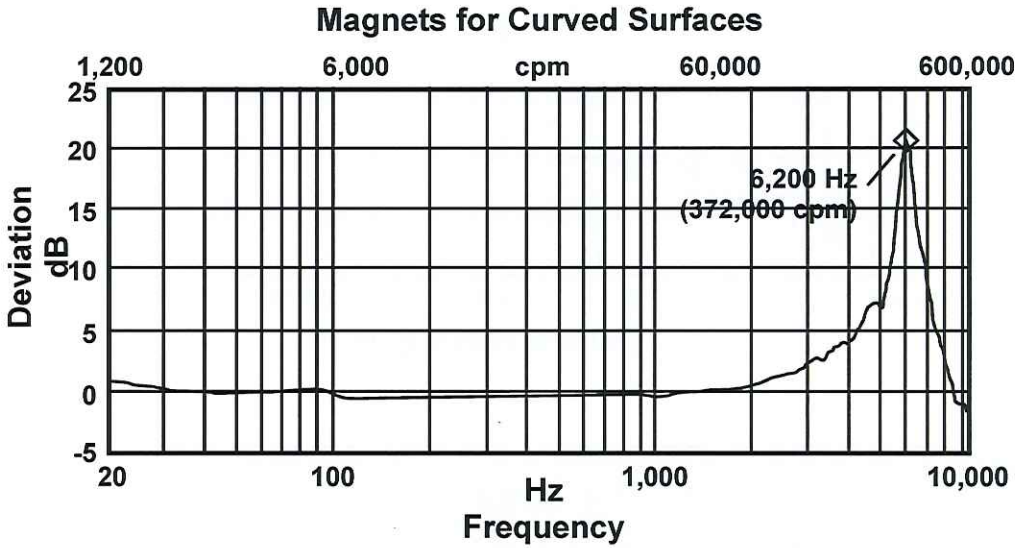
Transducer Frequency Response for Magnets on Curved Surfaces



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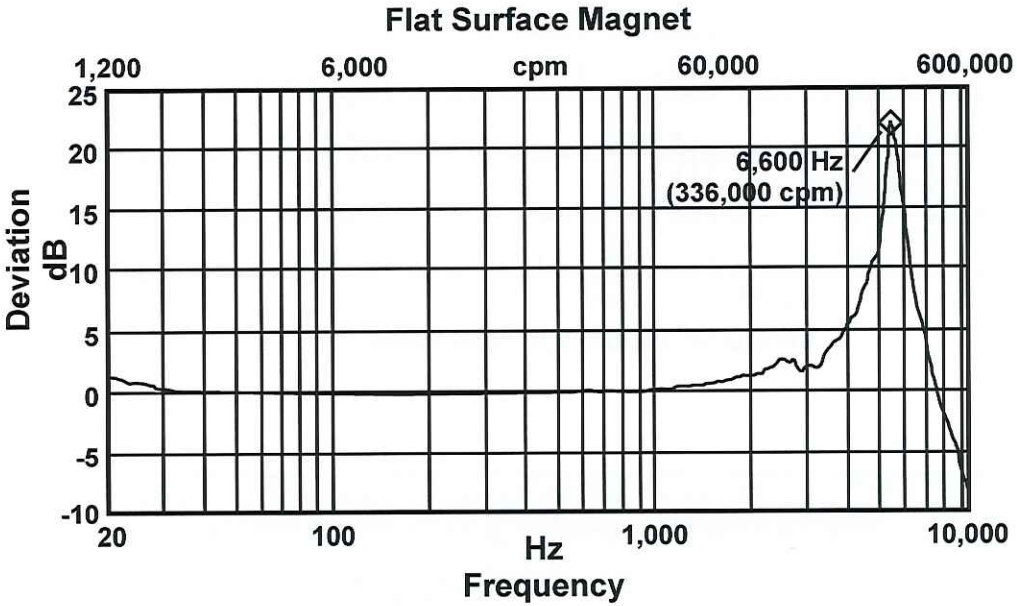
Transducer Frequency Response for Magnets on Flat Surfaces



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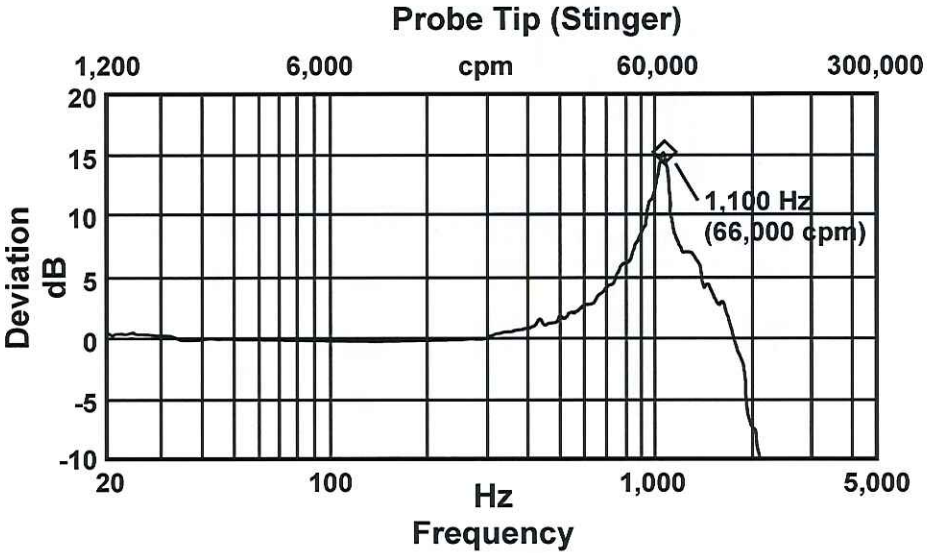
Transducer Frequency Response for "Stingers" or "Hand Held Probes"



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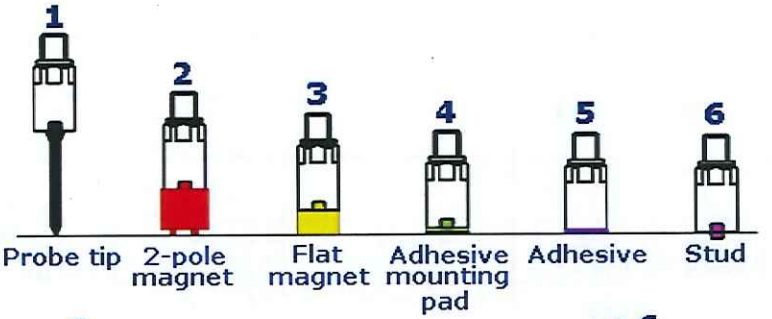
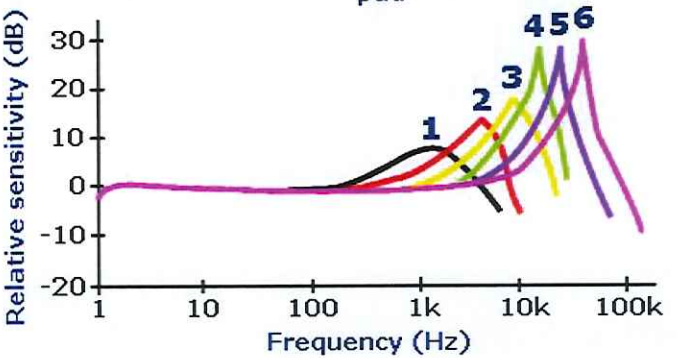
Transducer Frequency Response Curves





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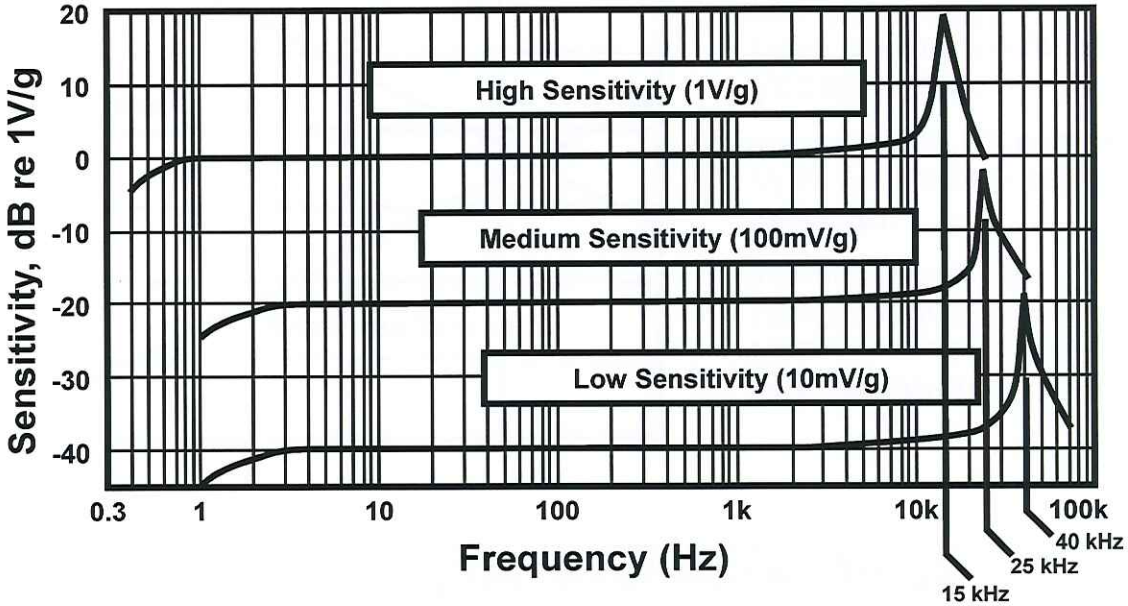
Transducer Frequency Response Curves for Accelerometers with Different Sensitivities



Transducer Frequency Response Curves for Accelerometers with Different Sensitivities

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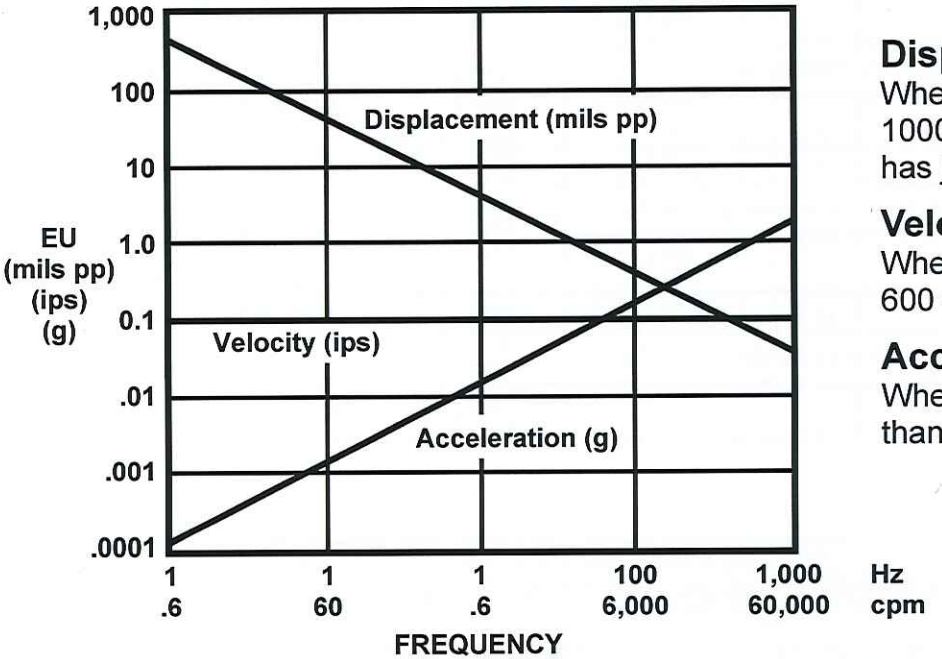
Transducer Effectiveness Regions



1607-R1

Displacement:
When the speed is less than 1000 CPM and the machine has journal bearings

Velocity:
When the speed is between 600 CPM and 120,000 CPM

Acceleration:
When the speed is greater than 60,000 CPM

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Thank You

Many thanks to the following companies for the use of their material:

DLI Engineering

IMI

Wilcoxon Research

Hewlett Packard - Application Note 243-1
DYNAMIC SIGNAL ANALYZER APPLICATIONS
Effective Machinery Maintenance Using Vibration Analysis

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Vibration Guideline Chart

Symptom	Most likely	Other Possible Causes	Page
1X Running Speed	**Imbalance** See page D-3	Misalignment Bent Shaft Looseness Eccentric journals, gears or pulleys Broken/cracked rotor bars (pole pass around 1X) Reciprocating machine (two-stroke engine)	D-13 D-16 D-18 D-54 D-37 D-32
2X Two Times or First Harmonic	**Misalignment** (High Axially) See page D-13	Looseness: just 1X, 2X, & 3X Looseness: lots of harmonics Bent shaft	D-18 D-18 D-16
3X Second Harmonic	**Misalignment** See page D-13	Cocked bearing Rotating element (vane, blade, etc.)	D-17 D-29
4X Fourth harmonic	**Coupling Problem** See page D-52	Coupling problem Severe misalignment Rotating element (vane, blade, etc.)	D-52 D-13 D-29
5X-8X	**Vane Passing** See page D-29	Rotating element (vane, blade, etc.)	D-29
0.39X-0.48X	**Oil Whirl** See page D-24	Oil whip	
0.5X Half Running Speed	**Rub** See page D-32	Rotor rub (sleeve bearing) Severe looseness (0.5X, 1X, 1.5X, ...) Drive belt resonance (could be >1X) Reciprocating machine (four-stroke engine)	D-22 D-18 D-56 D-32
Sub-Synchronous	**Belt Wear (Harmonics)** See page D-53	FTF Fundamental Train Frequency Flow turbulence Transducer problem (ski-slope) Eccentric rotor (Pole pass freq) Hunting tooth problems (HTF)	D-26 D-30 D-3 D-35 D-51

Symptom	Most Likely	Other Possible Causes	Page
100 or 120Hz Line Sync Frequency	**Rotor Problem** See page D-38	Stator eccentricity Eccentric rotor (pole pass sidebands) Shorted laminations Phasing problems (1/3 PPF sidebands)	D-33 D-35 D-41
Synchronous Higher Frequencies	**Gears** See page D-43	Fan speed x # blades (Aerodynamic) Cavitation, impeller x # vanes (Hydraulic) Loose rotor bars (2xLF around RBPF)	D-29 D-31 D-38
Non-Synchronous Higher frequencies	**Bearing Defects** **Lubrication** See page D-26	Inner race – BPI (1X sidebands) Outer race BPO Ball Spin – BS (FT sidebands) Cage – FT (sub-synchronous)	D-26
Harmonics	**Looseness** See page D-18	Bearing wear (non-synchronous) Misalignment (1X-4X) Rotor rub Journal bearing wear Belt wear (BR harmonics) Gear faults (harmonics of gearmesh) Broken/cracked rotor bars (1X & PPF sidebands)	D-26 D-35 D-22 D-23 D-53 D-43 D-37
Sidebands	**Bearing Wear** See page D-26	Gear faults (1X around gearmesh) Rotor eccentricity (PPF sidebands around 2xLF) Broken/cracked rotor bars (pole pass around 1X) Loose rotor bars (2xLF around RBPF) Loose stator coils – synch. motor (1X around CPF) Phasing problems (1/3 PPF sidebands)	D-43 D-35 D-37 D-38 D-40
Raised Noise Floor	**Severe Looseness** See page D-18	Severe bearing fault Cavitation (high frequency) Resonance (raised in small region) Transducer problem Flow turbulence	

Resonance can coincide with any dominant forcing frequency. See page D-25.

LF	**Line Frequency**
NF	**Noise Floor**
SS	**Sub-Synchronous**
NS	**Non-Synchronous**
S	**Sidebands**
H	**Harmonics**
3X-8X	**3X - 8X**
2X	**2X**
1X	**1X**

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